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Investigation into the Coefficient of Friction of Manual Therapy Products

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INVESTIGATION INTO THE COEFFICIENT OF FRICTION OF MANUAL THERAPY PRODUCTS

E.M. HOWES

Abstract

The ability to modulate friction is a vital aspect of manual therapy. Various mediums are utilised to assist with different techniques in the form of: lotions, oils and waxes. The aim of this research was to investigate the differences in the dynamic coefficient of friction between manual therapy mediums. A scientific testing rig with an interchangeable calibration weight (SE-8708, PASCO, USA) was pulled across the mediums and the force was recorded. Constant velocity was confirmed by monitoring acceleration via a wireless force-acceleration sensor (PS-3202, PASCO, USA). The coefficient of friction for each medium was calculated and recorded. Results showed the mean dynamic coefficient of friction for wax was 0.30 (95% CI, 0.26 - 0.35). This was significantly different from cream 0.16 (95% CI, 0.13 - 0.19) p=0.000 and oil 0.09 (95% CI, 0.07 - 0.12) p=000. There was also a statistically significant difference between cream and oil p=0.037. These results suggest that oil and wax produce the lowest and highest coefficient of frictions respectively. Therefore, if the intention of a technique were to increase friction, then wax may be the most effective medium. Alternatively, where less friction is required, oil may prove more efficient for the practitioner.

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1. Introduction

The ability to modulate friction is a vital aspect of manual therapy allowing for the optimisation of manual therapy techniques end efficacy of interaction between clinicians and clients. As such, the market for manual therapy mediums generates significant profits every year. Despite high sales, scientific research regarding the impact of the coefficient of friction on product performance appears limited. These mediums exist in various forms, with the most common being: creams, oils and waxes. The incorporation of lubricants between two surfaces can alter frictional forces dependent on molecular interaction (Bushan *et al.,* 1995). With this being evidenced, it can be assumed that the application of manual therapy mediums can also affect the resistance and ultimately impact the coefficient of friction. Practitioners involved in manual therapy will often use products assumed to affect friction rather than because of scientific research. For example, cosmetic oil is less viscous in comparison to wax-like products so has a lower coefficient of friction, therefore is claimed to be more effective for treatments requiring less friction (Martin, 2007). Conversely, powders are stated to have a low glide coefficient so are best suited for deep tissue treatments (Casanelia & Stelfox, 2009). Similarly, variations of the same products state different viscous properties and thus different coefficients of friction. In addition, practitioners purchase these products based on their alleged benefits as proposed by marketers. With benefits being stated as having anti-inflammatory properties, being non-comedogenic, hypoallergenic and being odor-free. Alternatively, these products are often purchased based on patient preference or economical value.

Therefore, due to the lack of substantial evidence, it is the purpose of this research to determine the differences between the coefficient of friction of different manual therapy products with the intention to allow for optimal interaction between clinicians and clients during soft tissue therapy, in order for improved efficacy of treatments and provide evidence to support current practices in Sports Therapy.

It is expected that the application of manual therapy mediums will cause a decrease in the coefficient of friction. This assumption is based on current knowledge and research that lubricants decrease the coefficient of friction between surfaces as a result of film and boundary layers (Zhang & Meng, 2015; Tang *et al.,* 2013).

It is often reported amongst practitioners and widely utilised in practise that the addition of oil allows for a decrease in the coefficient of friction (Norris, 2013; Karageanes, 2005). This is evidenced via the ability to provide gliding strokes during an effleurage technique (Paine, 2015). If friction were not affected, movement across the skin's surface would be limited.

Hypotheses

H^1 - There will be a statistically significant difference both amongst the three types of tested manual therapy mediums and from the baseline measurements

H^2 - There will be a statistically significant difference between cream and oil

H^3 - There will be a statistically significant difference between cream and wax

H^4 - There will be a statistically significant difference between oil and wax

2. Friction

Review of Literature

2.1 Definitions

Friction is an integral part of daily activities, and understanding its behaviour is an important aspect for manual therapy application. Friction is used during every day activities such as walking, driving and grasping objects. Bhushan (2013) describes friction as being the tangential reaction force between two surfaces in relative contact. When discussing friction, there are several different types.

Dry friction describes the force that opposes one surface from sliding against another and can be either static or dynamic. The force required to initiate movement is known as the static frictional force (F*fs*), whereas the maintenance of movement is achieved via dynamic frictional force (*Ffk*) (Armstrong-Helouvry, 2012). Consequently, dynamic friction commences once static friction has been overcome. Therefore, dynamic friction is possible only when the applied force is greater than the frictional resistance. Figure 1 demonstrates how this is represented on a graph.

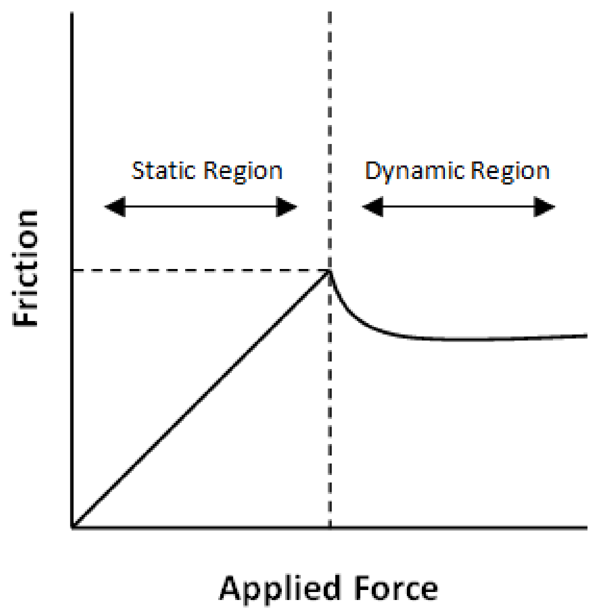

Figure 1 Graph demonstrating static and dynamic regions, adapted from Deutsch (2017)

When measuring the degree of frictional force between two surfaces, the coefficient of friction is utilised. The coefficient of friction is unitless but is often represented by the Greek symbol ‘μ’. The equation to calculate the coefficient of friction is as follows (Amontons, 1969):

$$\mu = \frac{\text{Frictional Force } (F)}{\text{Normal Force } (N)}$$

Different material pairs will display different coefficients of friction even if the applied normal force is the same for both. The coefficient of friction is influenced by numerous parameters such as material properties, surface roughness, normal load, sliding velocity and thermal effects which makes obtaining the coefficient of friction a challenging process (Nosonovsky & Mortazavi, 2013; Popov, 2010; Bowden & Tabor, 2001). A high coefficient of friction value means more force is required for movement to occur, in comparison to a low value meaning less force is required for movement to occur. The variance amongst friction coefficient tabulations within the literature can be attributed to these contributing parameters, which explains why no single number exists for materials. For example, research by Blau (2001) shows that within the literature the coefficient of friction from two wooden surfaces can vary from 0.25 to 0.62. It is worth noting that the research sourced for this study expanded over 40 years and within this time advancements to friction measurements had been made, consequently one should be wary when making comparisons. Nonetheless it highlights the discrepancies between measurement devices as well as influencing variables. As such, it has allowed testing for future research, including this current research to become more controlled with the inclusion of measuring acceleration and load more accurately.

Depending on the circumstance, the amount of friction is either beneficial or detrimental to daily living or tasks. Sport highlights the necessity for different degrees of friction. In racket sports, materials exhibiting high coefficients of friction are utilised to allow for optimal grip properties (Fuss, 2013). Similarly, in field sports, athletes require footwear that has a high coefficient of friction to allow for a greater frictional force between their feet and the ground, whereas skiers will apply wax to purposefully decrease the coefficient of friction (McGinnis, 2013). Although during this study, the application of wax was intended to reduce the coefficient of friction, the authors did not stipulate the evidence behind their choice of lubricant, nor did they compare it with other lubricants allowing for the possibility of another lubricant providing more optimal results.

In daily living, friction is apparent when walking to prevent slipping. According to the health and safety at work summary statistics for Great Britain (2016), 19% of workplace accidents are a result of slipping or falling. Swensen (1992) discovered that a loss of traction was the reason behind slipping and found that a coefficient of friction value between 0.20 to 0.40 resulted in a loss of footing. A vast amount of research exists looking to the degree of friction on floor surfaces and soles of footwear to reduce the rate of slipping by ensuring these materials display the most efficient coefficient of friction value (Morio *et al.,* 2017; Cowap *et al.,* 2015; Kleiner *et al.,* 2015; Hasouna and Ali, 2008; Ezzat *et al.,* 2008). Based on the same principles, if research exists detailing the effect of friction within the sporting environment and during daily activities, then it can be presumed that an effect will also occur within manual therapy and its products, however this is yet to be established.

2.2 Laws of Friction

The methodologies used have evolved through the years and research by Professor Hutchings (2016) details the first known documentation of frictional investigations by Leonardo da Vinci in 1493. He documented two laws of friction which although not published, were later confirmed by Guillame Amantons in 1699 and further developed by Charles-Augustin de Coulomb in 1785.

The first law states: The force of friction, *F,* acting between two sliding surfaces is proportional to the load, *W,* pressing the surfaces together. $F = \mu W$.

The second law states: The force of friction is independent of the apparent area of contact between the two surfaces.

A further law developed by Charles-Augustin de coulomb states: Dynamic friction is independent of sliding velocity.

2.2.1 Load

A study conducted by Pitenis *et al.* (2014) replicated one of Da Vinci's first experimental designs testing friction, and supported his findings, thus corroborating the first law of friction. Though the authors did not state whether this was of any significance, they found when doubling the load of a wooden block from 2.1kg to 4.2kg the force of friction increased.

Jiang *et al.* (2008) support this and looked at the impact load had on the coefficient of friction. They looked at the effect 5, 10 and 20N had on thermoplastic olefins using a sliding contact friction probe measurement. They discovered a 27% increase in the coefficient of friction from 0.37 to 0.47 when the load increased from 5N to 20N. Unlike Pitenis *et al.* (2014), they controlled the co-variables to improve the study validity by taking surface roughness into account together with acceleration. Results cannot be directly comparable though, as Jiang *et al.* (2008) measured the coefficient of static friction rather than dynamic.

Likewise, Yifu (2017) determined the effects of different loads on the coefficient of friction of steel coatings on steel. They used a ball on plate set-up and applied varying loads of 40, 80 and 120N. Their findings are similar to that of Pitenis *et al.* (2014) and Jiang *et al.* (2008) and found as load increased, coefficient of friction did also. However, it's worth noting that with the higher load, the coefficient of friction fluctuated and was not as stable and consistent as it was during the lower loads of 40 and 80N. Despite this, the coefficient of friction increased by 6.8% from 40 to 80N, 58% from 80 to 120N, and 68% from 40 to 120N. Perhaps this indicates that the greater the load the more unstable findings become. This could be as a result of deformation of the surfaces of both materials due to the increased pressure. These percentage increases were a lot greater than that of the findings from Jiang *et al.* (2008), possibly as a result of greater loads used.

Not all studies comply with Amontons' laws. Chowdhury *et al.* (2012) discovered the friction coefficient to be inversely proportional to load. This study revealed a decrease in the dynamic coefficient of friction as a result of an increase in load when investigating the difference between material pairs. This was evidenced by a 21% decrease in friction between two copper materials when the normal load increased from 10 to 20N, similarly a 22% decrease between brass materials as load increased. The fact that not all studies are in agreement with Amantons' law suggests that differing co-variables will affect overall results, and that these contributing factors need to be taken into account when making comparisons within the literature.

2.2.2 Area of Contact

Contact area is another of the parameters that can influence the coefficient of friction. Pitenis *et al*. (2014) discovered that when varying the contact area of a wooden block from $150cm^2$ to $420cm^2$ the static coefficient of friction changed from 0.68 ± 0.04 to 0.72 ± 0.04 respectively. Thus, a similar static coefficient of friction was found. They did not however state whether this was of any statistical significance. The similar scores seem to coincide with the 2nd law of friction that force of friction is independent of the area in contact between two surfaces. Gratton and Defrancesco (2006) found similar results when varying the contact area of aluminium. Like Pitenis *et al*. (2014), they failed to state whether their results were of any significance but appeared to imply that this agreed with the law of friction, stating that the force of friction is independent of the apparent area of contact between the two surfaces. The authors ensured that load and velocity were maintained to ensure consistency and tested four different contact area sizes ranging between 11-$65cm^2$. The coefficient of friction values from this ranged between 0.14-0.17, thus demonstrating the relatively small difference. However, what the authors failed to indicate, was how many runs was performed per area of contact.

2.2.3 Sliding Velocity

The third law of friction states that dynamic friction is independent of sliding velocity. This is supported by Chowdhury *et al.* (2012). They looked at the effect of sliding velocity on the coefficient of friction. When testing the coefficient of friction at 1,2 and 3m/s they found a minimum and maximum increase of 22.9% and 34.2% between different material pairs from 1m/s to 3m/s respectively. These results indicate that friction coefficient increases with the increase in sliding velocity thus supporting the third law of friction.

Despite this belief, a study conducted by Gunes (2015) found otherwise. This study looked at the effect of sliding speed on the friction behaviour of two types of steel using a ball on disk test device. Increasing the sliding speed from 0.1 to 0.5m/s, it was found that the coefficient of friction decreased by 31% and 36.5%. Although this contradicts with the findings of Chowdhury *et al.* (2012) the author attributes this decrease in coefficient of friction to oxide formation on the surface which allowed for the decrease or as a result of frictional heat. This could also be due to the application of alcohol after each test session, thus adding a layer of potential lubrication and consequently decreasing the coefficient of friction. Or perhaps the contrasting outcome is a result of much slower velocities employed by Gunes (2015) in comparison to Chowdhury *et al.* (2012).

2.2.4 Surface Texture

Traditionally, smooth and slippery textures exhibit low coefficient of friction values, whilst rough surfaces have a high coefficient of friction value. For example, when tested on skin, ice has been shown to have a friction coefficient close to 0 (Kietzig *et al.*, 2010), whereas sandpaper has a friction coefficient of approximately 1.36 (Gee *et al.*, 2005) and rubber 2.5 (Fuss *et al.*, 2005). Pitenis *et al.* (2014) also looked at the effect of surface texture on force of friction. The authors adjusted their experimental procedures by modifying the surface textures of the wooden blocks. Subsequently, the coefficient of friction between each block differed quite substantially, with a coefficient of friction of 0.72 for a smoothed and sanded block compared to 0.35 for a sullied block. Despite not stating whether this was statistically significant, the results still highlight the sensitivity of static friction to surface roughness.

These findings have important implications when selecting testing parameters for the current study. This means the co-variables such as measures of load, velocity and surface texture need to be as controlled as possible to sustain high validity within the research.

2.3 Testing Methods

The number of parameters that influence the coefficient of friction highlight the importance of ensuring friction modelling and methodology is consistent. Furthermore, the utilised methods need to meet the demands of the desired outcome to obtain the most reliable and accurate results. Several methods are employed to measure friction coefficient with them differing substantially within the literature. Some studies report using Pulleys (Gratton and Defrancesco, 2006), pin-on-disc (Chowdhury *et al.,* 2012), ball-on disk (Gunes, 2005), frictionmeter (Zhu *et al.,* 2011), pulley systems

(Pitenis *et al.,* 2004) and inclined planes (Bejo *et al.,* 2000). The pin-on-disc method appears to be the most utilised method, this is likely due to its ability to control load and speed, as well as the capability to run continuously. It has also been shown that due to this, the pin on disc method is very reliable (Hegadekatte et al, 2008). On the other hand, this method is expensive and only appears to measure over a small area. This is not realistic of some manual therapy techniques where friction takes place over a larger area. Furthermore, repeated friction movements over the same small area could lead to wear which consequently could affect the outcome for the coefficient of friction. Other studies on cosmetic emollients have previously utilised a 'perceived skin feel' method as a means to evaluate the coefficient of friction on the skin (Nacht et al, 1981). This process is cheaper than utilising expensive equipment and has been shown to have a positive correlation with mechanical measurements (Liu *et al*., 2008). Whilst the data has the ability to be specific to the individual, this method is outdated and cannot be deemed as significant due to being qualitative in nature. The method is unreliable and not replicable due to sensory differences between participants and alterations in the participants' physiological and psychological state (Egawa *et al.,* 2002) Therefore it is necessary to obtain objective results via instruments. Lewis *et al*. (2007) adopted an in vivo approach with the use of instruments. The research involved subjects slowly sliding an index finger across a counter face at a 30° angle at an approximate load of 20N. Although the findings corresponded with previous research, it was stated that the methodology was unreliable and required adjusting. One reason for this is that it is not possible for humans to maintain a constant load and sliding velocity, which has previously been stated to affect friction. To eliminate this limitation, subsequent studies have employed the use of a mechanical probe instead. Vilhena and Ramalho (2016) obtained skin friction measurements using a mechanical probe. The benefits of using the probe were that a consistent sliding velocity, distance and load could be applied. This can be applied to skin in a similar manner to a massage stroke, so the application of this method would be valid to the target population to the current study. However, the curvature of the probe can significantly affect the results obtained due to the deformation of skin when the external force is applied which is detrimental to reliability (Srinivasan *et al*., 2002). In addition to this, further studies researching skin friction via mechanical probes have stated problems with reliability (Gee *et al*., 2005). However, this can be attributed to the nature of skin such as levels of hydration, temperature and wear from repeated trials, as opposed to the measuring instruments. Hand-held devices appear popular during the assessment of skin friction due to the portability and ease of various areas on the body. However, being hand-held makes it difficult to sustain velocity without irregularities. Gratton and Defrancesco (2006) utilised a sliding-pulley system. The authors attached an accelerometer to a moving cart which allowed for measurement of both force and acceleration. The measurement distance was not restricted therefore would allow for replication of manual therapy techniques whereby longer strokes are provided to larger areas of the body in a linear motion. Not only this, but this testing method is less expensive, more portable and requires less training than other instruments used. Although appears to be a simpler method for the measurement of the coefficient of friction, results obtained coincide with Amontons' Laws of frictions and results of that reproduced via other methodologies thus proving to be a reliable testing method with valid outcome measures. Therefore, these reasons ultimately influenced the method of this current research

3. Skin

Review of Literature

3.1 Structure of Skin

Human skin is the most extensive organ in the human body and acts as an interface between the human body and the environment. It is composed of three major layers - the epidermis, dermis and hypodermis (Figure 2). The epidermis is made up of epithelium and is the outermost layer of the skin, serving as a waterproof and protective barrier against pathogens (Zaidi and Lanigan, 2010). Below the epidermis is the dermis which is comprised of collagen fibres to provide the skin with strength, elastin to provide the flexibility to the skin and keratin fibres to allow for water repellence. Whilst it has been discovered that there are at least 27 types of collagen in mammalian tissues, type I is the most abundant (Van der Rest and Garrone, 1991). The structure of type I collagen molecules consists of three polypeptide chains that coil around each other to form a triple helix. These collagen molecules then assemble with other collagen molecules, bonding via covalent cross links and forming collagen fibrils (Fratzl, 2008). This fibrillar structure is built to resist tensile, shear and compression forces, therefore providing strength to the dermis (Shoulders and Raines, 2009). The role of elastin is to return the dermis to its original state after an external force has been applied (Debelle and Alix, 1999). This is achieved through the structure of elastin as it is composed of many tripoelastin molecules that confer elasticity via lysine mediated cross linking (Piontkivska *et al*., 2004). Both collagen and elastin work in conjunction to create an interlocking mesh within the dermis known as the dermal extracellular matrix. This is a very complex structure that allows for dynamic movement of the skin and to exhibt both strength and flexability (Langton *et al.,* 2009).

Within the dermis are many nerve endings that allow for sensation, as well as hair follicles, sweat glands and vessels (Habif, 2015). The hypodermis is below the dermis and is made up of connective tissue and adipose tissue. Although not part of the skin, the hypodermis attaches the skin to the bone and muscle and supplies it with blood vessels and nerves (Montagna, 2012). The structure of the skin is an important consideration for manual therapists as it provides an insight into what is being palpated which allows them to establish the degree of pressure to apply depending on the target area.

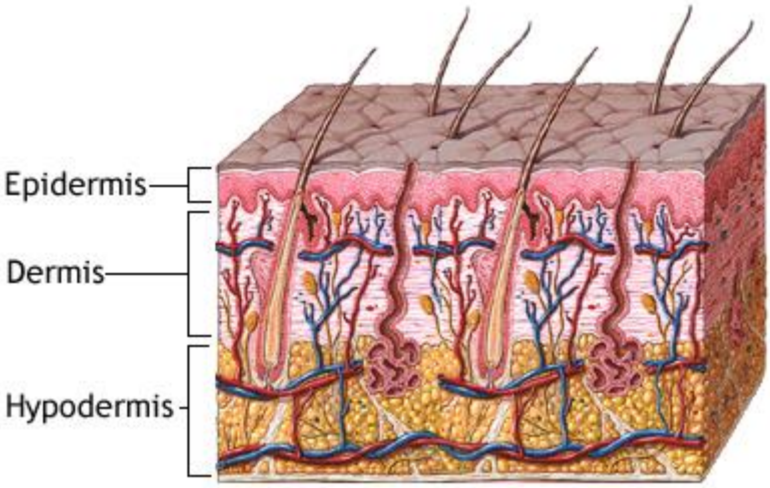

Figure 2. Schematic structure of human skin layers from the American Accreditation HealthCare Commission (2017)

3.2 Function

The skin is responsible for numerous bodily functions, with the main functions shown in Figure 3. The epidermis serves an important role in protecting the body from the external environment and protects it from mechanical impacts and pressure (Montagna and Lobitz, 2013). The intention is to prevent skin lesions which would consequently impede the functionality of the skin. If, however this is not possible, and impact is stronger than the skin, then a wound will occur (Percival and Cutting, 2010). The skin also acts as a barrier against micro-organisms and is the first line of defence against infection and shields the body against UV radiation from the sun via the melanin in the skin (Stone, 2004). The skin also protects the body by retaining the fluids and moisture within the body via the sebum secreted whilst the keratin within the skin simultaneously prevents absorption of unnecessary fluids from the environment (Scott and Fong, 2013). This is how we can stay hydrated following drinking and swim without absorbing the water like a sponge would. The skin also aids in homeostasis by regulating body temperature via perspiration and hair to prevent temperatures that are either too high or too low (Zaidi and Lanigan 2010). In addition to this, it notes changes in peripheral circulation and fluid balance. The nerve cells within the skin are responsible for sensation and can detect changes in temperature, texture and pain. Disruption to these cells alters reception and consequently sensation such as with peripheral neuropathy (Said and Krarup, 2013). Another main function of the skin is endocrine function for the synthesis of vitamin D (Thibodeau and Patton, 2013; Montagna, 2012).

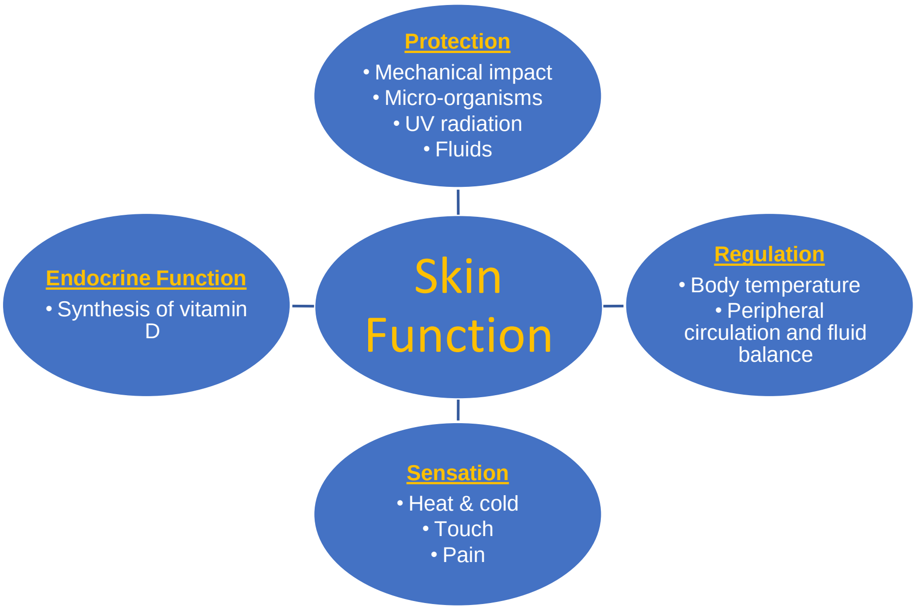

Figure 3. Main Functions of the Skin

3.3 Skin Properties

The biomechanical properties of the skin are determined by a series of networks within the dermis that are constantly changing as a result of environmental, physiological and biomechanical factors (Pawlaczyk *et al.,* 2013). These properties can alter the way in which the skin reacts with the environment, and can be as simple as cosmetic application, perspiration, water and dirt (Hussain *et al.,* 2013).

3.3.1 Skin Viscoelasticity

Collagen, elastin and ground substance are the main components of human skin and determine the properties of the skin. Collagen is the most abundant protein within our bodies and is responsible for providing the skin with tensile strength and support (Bronzino, 1999). In comparison, elastin allows for the extensibility that collagen opposes and is responsible for the recoil of skin following applied stress (Bronzino, 1999). Between these fibres are the ground substances which help with lubrication during movement. The combination of both collagen and elastin fibres make the skin viscoelastic in nature, in that the skin displays both viscous and compliant features during deformation (Subhi *et al.,* 2017; Silver, Freeman & DeVore, 2001). The compliance that the skin exhibits means only a small amount of stress is required for deformation to occur (Edsberg *et al.,* 1999). The degree of viscoelasticity that the skin exhibits is dependent on numerous factors that make up the skin's properties.

An increase in age is one of the many properties to affect the viscoelasticity of the skin. Studies have shown skin compliance to be age dependent with a decrease in compliance as a result of increasing age (Luebberding *et al.,* 2014; Firooz *et al.*, 2012; Krueger *et al.,* 2011). A study conducted by Pittet *et al.* (2014), discovered a 23% decrease in skin compliance which they attributed and confirmed to a significant reduction in the amount of collagen and elastin with the older aged participants as measured via multiphoton microscopy. Anatomic location was also found to be a significant independent factor for elasticity (Firooz *et al.*, 2012).

3.3.2 Skin Thickness

Skin thickness is another factor that affects the biomechanical properties of the skin (Nemoto *et al*., 2012). Typically, the thickness of the stratum corneum varies between 10 μm and 30 μm, and is reported to be age, gender and site dependent (Böhling *et al.,* 2014; Tagami, 2008). Anatomical location offers the biggest variation for inter-individual differences. Ya-Xian (1999) reported vast differences in the amount of cell layers within the stratum corneum with the smallest amount being found in the genital skin and largest amount in the palms and soles. Differences in stratum corneum thickness between anatomical locations have further been supported by other authors as summarised in Table 1. With the thickest area being the back of the hand as reported by Egawa *et al. (*2007). Stratum corneum thickness was measured using a confocal Raman spectroscopy which despite its merits can be influenced by hydration levels. This makes it difficult to compare sites between different studies when studies have proven that hydration levels can impact the results of apparent skin thickness measurements (Bouwstra *et al.,* 2003). Although it does evidence that variations do exist at different areas of the body. Sandby-Moller *et al*. (2003), Crowther *et al*. (2008), and Egawa *et al*. (2007) each measured the skin thickness of three or more different anatomical locations. As evidenced in Table 1, values differ on the same body part between different studies showing potential differences between study designs and participant differences. This is highlighted with the forearm displaying different values. Table 1 also evidences the variability in skin thickness among different anatomical locations when observing each study individually. This is important for manual therapists as it can contribute towards client comfort. Areas of the body demonstrating a lower skin thickness may not tolerate an application of high friction as well as a location with a greater skin thickness.

Table 1. Stratum corneum thickness at different anatomical locations

Author	Test area	Mean stratum corneum thickness (µm)
Egawa et al.	Cheek	16.8 ± 7.84
	Upper arm	21.8 ± 3.63
	Volar forearm	22.6 ± 4.35
	Back of hand	29.3 ± 6.84
Crowther et al.	Cheek	12.8 ± 0.9
	Volar forearm	18.0 ± 3.9
	Leg	22.0 ± 6.9
Sandby-Moller et al.	Dorsal forearm	18.3 ± 4.9
	Shoulder	11.0 ± 2.2
	Buttock	14.9 ± 3.4
Pirot et al.	Forearm	12.6 ± 5.3
Kalia et al.	Forearm	12.7 ± 3.3

3.3.3 Hydration of the skin

The stratum corneum is responsible for the control of water entering and leaving the body. It is approximated that in the case of healthy skin, there is a daily transepidermal water loss of 0.5L (Marks, 2004). The degree of transepidermal water loss depends on a variety of factors with the main being due to environmental humidity (Agache and Humbert, 2004). Another contributing factor of skin hydration includes the covering of the outer surface of the stratum corneum with cosmetic films such as creams and moisturisers, or via sweat or rainfall (Wissing and Müller, 2003). This may have an impact on what type of medium clients opt to be applied if this can lead to more hydrated skin rather than taking the frictional properties into consideration.

The hydration levels of the skin can have a significant influence on its properties (Liu *et al.,* 2016; Edwards and Marks, 1995). Huang *et al.* (2013) describes a connection between a decrease in skin hydration and skin fissures and irritation, skin roughness and ineffective transepidermal water loss.

Choi *et al.* (2013) found a significant negative correlation when measuring wrinkle parameters and hydration, as well as a positive correlation for hydration and skin elasticity. This is further supported by Dobrev et al. (2000) who showed that applying emollients to the skin and thus increasing its hydration levels increased the skin elasticity. This being a reason why cosmetic and manual therapy companies advertise creams and lotions as a means to help with the skin and provide a certain benefit (Jemec *et al., 1990*; Dreno *et al.,* 2014). These benefits appear to be more supported more within the cosmetic industry than with manual therapy mediums.

3.4 Skin and Friction

As the main barrier between the body and the environment, the skin is exposed to a variety of materials daily. It's interaction with these materials means skin friction plays a pivotal role in daily living. For example, during tactile perception (Kuilenburg *et al.*, 2015; Adams *et al.,* 2013), cosmetic application (Tang *et al.,* 2010), sporting activities (Lewis *et al.*, 2014; Fuss and Niegl, 2012) and when grasping objects during everyday tasks (Uygur *et al.*, 2010).

The coefficient of friction of human skin is dependent on the material and surface properties of both the skin and the contacting surface, contact parameters and potential substances present on the skin (Derler *et al.,* 2009). Due to the biomechanical properties of human skin, the same principles of friction that follow Amonton's law are believed not to apply to skin (Comaish & Bottoms, 1971). Instead, skin is thought to react in a similar way to that of elastomers, whereby adhesion and deformation contribute towards the overall coefficient of friction (Subhi *et al.,* 2017). Adhesion between human skin and a contacting surface is resultant of bonds formed between them (Buckley, 1981). The resulting frictional force between these two surfaces depends on the amount of force required to shear these bonds. Like elastomers such as rubber, human skin displays a low Young's modulus, meaning skin displays little stiffness and thus less force is required to increase the surface contact area of the asperities between the two surfaces, consequently forming more bonds (Al-Assi and Kassem, 2017; Vegas and Del Yerro, 2013).

In elastic based friction, greater surface contact area allows for a greater number of the aforementioned adhesive bonds to be formed. This means that the frictional force imposed on an elastic surface is proportional to the contact area between the two materials (Barquins and Roberts, 1986). Barquins and Roberts (1989) describe that when a hemisphere of rubber slides along a flat piece of glass (or vice versa), the frictional force is equal to (contact force)$^{2/3}$. However, skin is not completely flat or a perfect hemisphere, containing many ridges and creases such as fingerprints and wrinkles, therefore this calculation is not completely accurate when applied to skin. On the other hand, Warman and Ennos (2009) discovered that whilst the formula was not completely accurate when applied to the fingertips, the skin still exhibited rubber like properties similar to hemispherical or flat rubber. Therefore, the calculation can still be utilised to estimate the frictional force of skin, and is further evidence showing that skin does not conform to Amontons laws of friction.

Regarding skin deformation, Hertz's theory suggests that the area of contact of elastic materials and subsequent deformation is related to the load (Hertz, 1881). This coincides with the friction adhesion in creating a greater contacting surface area with the addition of load. Soneda and Nakano, (2010) are in agreement and used an optical technique to discover that both apparent and real contact areas of human finger pads increase with increasing contact loads as ridges are flattened. This is further supported by Warman and Ennos (2009) who found that an increase in load caused a flattening of fingertips which subsequently lead to a greater surface area and a resultant increase in the coefficient of friction thus supporting the non-conformity of Amonton's law.

Regarding skin friction and the impact of load, Van Kuilenburg *et al*. (2012) found the friction coefficient to be inversely proportional to load when researching tactile friction. Kwiatkowska *et al.* (2009) are in agreement and found when looking at friction on the forearm the coefficient of friction values decreased as the load increased from 0.19N to 0.5N. Although Sivamani, *et al.* (2003) support that friction coefficient is dependent on the normal load, they found that as the normal load decreased, the coefficient of friction increased. On the contrary, other studies have reported that the frictional force is proportional to the applied load (Tang *et al.,* 2008; Asserin, *et al.,* 2000). With recent work performed by Vilhena (2016) supporting Amonton's law by finding that frictional force was proportional to the normal load applied when assessing the friction between human skin and medical fabrics. This study provided good evidence of support by testing on various anatomical locations as well as in different hydrated states.

3.4.1 Skin Hydration and Friction

The degree of friction the skin exhibits is believed to depend on both water content on the skin and the amount of moisture present in the stratum corneum (Serup *et al.,* 2006). A common finding amongst the literature is that the presence of moisture within the skin or the application of water on the skin's surface causes an increase in the coefficient of friction and a sticky-like feel (André *et al.,* 2011; Man *et al.,* 2009; Gerhardt *et al.,* 2008). These findings are often attributed to the adhesion theory of friction (Persson, 2013; Tomlinson *et al.,* 2011). Wolfram (1983) suggests that this is due to the addition of water onto the skin's surface, which makes it softer which produces a lower Young's modulus which increases adhesion and consequently increases friction. Veijgen *et al*., (2013) support this theory and found a significant ($p<0.001$) positive correlation $R^2=0.23$ between skin friction and skin hydration. Although this demonstrates a noticeably low effect size, a relationship still exists nonetheless thus supporting this theory. The highest coefficient of friction was found at the index finger pad which also displayed the highest skin hydration level as recorded by a corneometer reading. When assessing the relationship between skin friction coefficient and stratum corneum hydration, Zhu *et al.,* (2011) also discovered similar results. However dissimilarly, their study consisted of a much larger participant size of 633 participants with differing ages and genders which allowed a more detailed differentiation between results. Because of this, it was discovered that the relationship between skin friction and hydration did indeed exist however was not significant at all tested body sites or consistently with both genders. Thus, the dependence of anatomical site, age and gender are affecting the overall results. This highlights that both above studies mentioned only used minimal site locations which may not be enough to differentiate the influence of skin hydration on skin friction coefficient.

3.4.2 Anatomic Region and Friction

Anatomical location is another influencing factor regarding skin friction whereby different locations all demonstrate different skin friction coefficient (Eisner *et al.,* 1990; Cua *et al.,*1990). Table 2 highlights the influence that anatomical location has on the coefficient of friction. The table indicates that the coefficient of friction can differ greatly when comparing two anatomical locations. When observing the studies of Zhang and Mak (1999) and Ramalho *et al*. (2007) the palm of the hand produced a greater coefficient of friction value than the anterior forearm. However, the table also shows that there are inconsistencies of anterior forearm friction between the various studies. The values range from as low as 0.15 (Ramalho *et al.,* 2007) to as high as 1.63 (Elleuch *et al.,* 2006), which is a drastic difference. This would suggest that there are many external factors affecting coefficient of friction, and it would be more reliable to compare locations tested in the same studies as opposed to similar studies. Zhu *et al.* (2011) used a rotating frictionmeter to assess the coefficient of friction of the dorsal surface of the hand, the forehand and canthus. They established a difference in the coefficient of friction between the three different anatomical locations. The coefficient of friction of the skin on the dorsal hand was significantly higher than that of the forehead in females aged 11-40. Similarly, the forehead displayed the lowest coefficient of friction in males aged 21-50 in comparison to the canthus and dorsal hand. Despite no significance between anatomical locations in other age categories, it is evident that a difference between body sites exists with the dorsal hand displaying the highest coefficient of friction and the lowest found in the forehead. Zhu *et al.* (2011) attribute these differences in skin friction to different anatomical locations displaying different hydration levels. As aforementioned, Veijgen *et al.* (2013) also found skin hydration to contribute to the variability in skin friction at different anatomical sites. This is further supported by Firooz *et al.* (2012) whereby anatomical location was a significant independent factor for various biophysical parameters of the skin. Despite comparative literature, most studies only look at one certain area of the body rather than comparing across upper and lower limb which could serve as interesting comparison.

The difference in skin frictional coefficient within the literature highlights the fact that anatomical location cannot be representative of other locations when measuring skin friction. This is particularly the case in manual therapy as various locations are often worked upon during manual therapy application for both the therapist and patient as often clinicians will use hands, forearms and elbows. The interaction between these different body parts can consequently affect the coefficient of friction.

Table 2. Coefficient of friction values at different anatomical locations

Author	Test area	Coefficient of friction
Zhang & Mak (1999)	Dorsal hand	0.47±0.12
	Palm of hand	0.62±0.22
	Anterior forearm	0.46±0.1
	Posterior forearm	0.43±0.1
	Anterior leg	0.4±0.1
	Posterior leg	0.4±0.09
Batt *et al.* (1988)	Anterior forearm	0.2±0.01
Egawa *et al.* (2002)	Anterior forearm	0.24±0.05
Ramalho *et al.* (2007)	Anterior forearm	0.15±0.034
	Palm of hand	0.9±0.26
Kwiatkowska *et al.* (2009)	Anterior forearm	0.7-1.2
Elleuch *et al.* (2006)	Anterior forearm	1.63±0.07

3.4.3 Surface Roughness/Texture and Friction

The surface of human skin is covered by many ridges and furrows which consequently influences the surface roughness of the skin (Derler and Gerhardt, 2012). Skin dryness is also reported to be a contributor towards the degree of surface roughness the skin exhibits (Eberlein-KoeNig *et al.*, 2000). No one number exists for the surface roughness of skin, instead this varies amongst individuals and differs between anatomical sites (Gerhardt *et al.,* 2009). Surface roughness is one of many influencers towards the coefficient of skin with Hendriks and Franklin (2010) reporting a significant influence of the surface roughness of skin on the coefficient of friction (R2 = 40%, p = 0.000). The work of Tomlinson *et al.* (2007) found the coefficient of friction between a hard surface and the skin to be inversely proportional. Research in this area appears to change the degree of roughness of the testing material rather than that of human skin. Therefore, the interaction between the two is seen but not the effect of surface roughness of skin itself. Although this can provide therapists with an insight, it is limited as the two contacting surfaces within manual therapy are usually both skin as opposed to a hard surface.

3.5 Skin friction and injuries

Although friction is extremely beneficial in assisting with everyday tasks, several studies suggest that too much friction has the opposite effect and can be detrimental to the skin (Sulzberger *et al.,* 1966; Tlougan *et al.,* 2011). An excess in friction to the human skin can lead to a separation of the epidermal cells which results in the formation of a blister (Knapik *et al.,* 1995). Friction related injuries in the form or blisters are common among runners, other sports people and those in the military (Farhadian *et al.,* 2013; Brennan *et al.,* 2012; Van Tiggelen and Dumalin, 2009; Mailler-Savage and Adams, 2006).

The European Pressure Ulcer Advisory Panel and the National Pressure Ulcer Advisory Panel (2009) state decubitis ulcers also form as a result of increased exposure to shear force and friction. This often occurs when bony prominences repeatedly rub against another surface often bed sheets or wheelchair seats. This is why research exists to manufacture materials that assist in reducing skin fiction between the skin compression stockings (Ke *et al.,* 2014) and bed sheets, especially of those in hospitals and care homes (Rotaru *et al.,* 2013; Shaked and Gefen, 2013).

According to Orsted *et al.* (2010) bedridden and elderly patients are more vulnerable to developing these injuries as a result of decreased skin elasticity due to age as well as difficulty in repositioning themselves without creating an excess of friction. Research also suggests the risk is greater due to the increase in moisture either from incontinence or leakage from dressings (Baumgarten *et al.,* 2006). This is further supported by Kirkham *et al.* (2014) who found that the formation of blisters were more likely if skin hydration was greater.

Surface related injuries are also found as a result of increased friction. Pasanen *et al.* (2008) found an increase risk of injuries in football players when playing on artificial turf due to an increase in friction between the surface and footwear. Additionally the rate of friction burns and abrasions were higher on artificial turf than grass due to increased friction of the surface (Ekstrand *et al.,* 2006).

Another friction related injury is folliculitis. Folliculitis is inflammation of the hair follicles and can often be as a result of physical irritation as a result of an increase in friction such as clothes rubbing or shaving or manual therapy (Craft *et al.,* 2011).

This highlights the importance of measuring the degree of friction occurring and finding the optimal level whereby it is still achieving the desired affects without being detrimental.

3.6 Synthetic/mechanical skin

Results are contradictory and inconclusive due to the many subject inter and intra variability. This explains why some studies use synthetic or mechanical skin in order to gain a standardised method when testing friction (Dąbrowska *et al.,* 2016; Guerra and Schwartz, 2011; Derler *et al.*, 2007; Ramkumar *et al*., 2003). Whilst the use of synthetic or mechanical skin removes the need for subjects, the viscoelastic nature of the skin can still cause inconsistencies when testing friction. As previously mentioned, this elasticity can cause varying amounts of surface contact during testing, thus ensuing in a range of results. To achieve consistency during repeated measures, it may be beneficial to test surface friction via a material with plastic properties as opposed to elastic.

4. Manual Therapy

Review of Literature

4.1 Introduction to Manual Therapy

Manual therapy involves an assortment of physical techniques designed to treat musculoskeletal pain and dysfunction. It is utilised by a range of health practitioners such as physiotherapists, chiropractors and osteopaths. Treatment is primarily applied through the use of the practitioner's own body in order to have fully control when manoeuvring limb position and applying pressure on muscles, however the use of equipment to achieve this is not uncommon (Medlicott and Harris, 2006).

4.2 Purpose of Manual Therapy

It is suggested that the purpose of manual therapy is to diagnose and treat musculoskeletal pain, discomfort and abnormalities (Koes *et al*., 1990). Muscle strains and hypertonicity, ligament sprains and joint degenerations are some common causes of musculoskeletal pain. These causes can originate through many means, for example structural overuse, intense activity, and prolonged unnatural posture (Linton, 2002). The modulation of pain and abnormality can be achieved in many ways, such as decreasing soft tissue inflammation, inducing relaxation of tense soft tissue, enhancing ROM and breaking down scar tissues (Bialosky *et al*., 2009).

4.3 Types of manual therapy

4.3.1 Manipulation

Manipulation in manual therapy involves a therapist utilising high velocity thrusts to manoeuvre limb position in a synovial joint beyond their normal end range of motion. The desired result of joint manipulation is to increase mobility and range of motion whilst decreasing any pain and relieving stiffness in the neighbouring muscles (Donatelli and Wooden, 2009). Potential risks can be described as mild in severity which is commonly discomfort, both locally and radiating. However, there are greater risks, albeit uncommon, regarding vertebral manipulations. Improper application can lead to vertebral disc herniation, fractures, strokes and paralysis (Powell *et al.,* 1993).

4.3.2 Mobilisations

Mobilisations are very similar in nature to manipulation, however differ biomechanically. Whilst both mobilisations and manipulation involve the passive motion of a limb to affect a joint, mobilisations occur within the normal range of motion for the joint and utilise gentler, less intense movements and oscillations (Koes *et al.,* 1991). The use of a strap or belt is often utilised to aid the clinician in manoeuvring the technique (Chevan and Clapis, 2012). Mobilisations are often performed on synovial joints and the spine. Maitland (1977) has expressed four grades (I-IV) of joint mobilisation. Grade I consists of the therapist creating small amplitude oscillating movements at the early range of movement prior to tissue resistance. Grade II and II are large amplitude oscillating movements before and after tissue resistance respectively. Grade IV is a small amplitude movement at the end range of movement. The mobilisation occurs until the end range of passive ROM, which is where the joint ROM cannot be gently increased anymore. If desired, this is when practitioners can implement a manipulation technique in order force the joint past a limited ROM into a normal ROM. It is for this reason that manipulations can also be classified as a grade V mobilisation (Saunders *et al.*, 2005).

With too little friction, the practitioners' hands would slide of the body part and these oscillations and high velocity thrusts would not be able to effectively take place. Often patients are sweaty or hairy, therefore it may be desirable for a medium to be applied to counteract this to gain ideal amount of friction.

4.3.3 Massage

Massage is by far the most well-known form of manual therapy and has been utilised and developed in almost all cultures for medical care (Vickers and Zollman, 1999). In Europe, massage has now evolved into what is widely known as Swedish massage. Although Swedish massage has had many definitions, it is largely agreed that the massage style involves differing techniques to relieve pain and discomfort. These are known as effleurage; petrissage; friction and tapotement (Ali *et al*., 2012).

Effleurage is a gentle entry stroke, used to introduce touch and relax the patient, spread medium, warm superficial tissues and allow the practitioner to palpate the skin and muscle conditions.

Petrissage is an advancement on the aforementioned effleurage. Greater force is applied to the stroke, to affect deeper tissues (Ogai *et al*., 2008). This increase in intensity is thought to stretch muscle fibres, reduce muscle tension and improve muscle mobility. It is also commonly thought that petrissage can lead to an increase in both venous and lymphatic return, however previous studies have shown inconclusive results, mainly due to design limitations (Weerapong *et al*., 2005). Common design limitations are small sample sizes (Hansen & Kristensen, 1973), no reported statistical analysis (Dubrivsky, 1983) and/or are lacking a control group (Hovind and Nielsen, 1974). Although these studies do not provide any statistical significance, there is an agreement throughout the studies that suggest that petrissage is a factor in increased venous and lymphatic return.

Tapotement involves striking tissues with various parts of the hand briskly. The suggested clinical advantage is that this neurologically stimulates the tissues, preparing the fibres for exercise (De Domenico, 1997). It is for this reason that many athletes undergo this treatment prior to competition. The most common tapotement techniques are known as hacking and cupping. Hacking is performed using multiple chops rapidly, with the lateral border of the 5th digit striking each time. Cupping is executed by creating a concave shape with the hand, then rapidly striking the desired area with the palm facing towards the tissues. However, there are currently no studies that show any neurological advantages gained through tapotement to support prior clinical claims (Gasibat and Suwehli, 2017).

Another technique commonly performed by practitioners is deep friction massage (Cyriax, 1984). Frictions involve an increase in intensity; however strokes are more localised and focused. The greater pressure is usually generated through the fingertips, thumbs and/or knuckles rubbing in circular motions or back and forth (Goats, 1994). The aim of frictions is to breakdown scar tissue caused from injury to regain elasticity and mobility in the tissues (Fernández-de-las-Peñas *et al*., 2006). Frictions are also utilised during healing phases in order to align new scar tissues (Schwellnus and Mee, 1992). In reviewing Cyriax's friction massage, Chamberlain (1982) states the degree of friction is important in achieving the most effective massage. With thicker and stronger structures, a greater friction needs to be applied perpendicular to the fibres, however an excess in friction over subcutaneous fascia against other structures can lead to injury. This demonstrates the importance of varying the amount of force applied with techniques and whether there are mediums or products that can be utilised to make this more effective.

4.4 Effectiveness of Manual Therapy Techniques

The aforementioned treatment modalities are highly debated within the literature with no definitive evidence to the effectiveness they provide. This is highlighted with a plethora of research whereby no single conclusive outcome exists.

Bennell *et al.* (2010) performed a randomised placebo controlled trial looking into the effect of manual therapy on chronic rotator cuff disease. Participants were assigned to either receive the manual therapy intervention or placebo. The active intervention consisted of mobilisations, manipulations, soft tissue massage and home exercises, whereas the placebo group received sham ultrasound and were not instructed to perform any home exercises. Initial results did not reveal a significant effect of the manual therapy intervention in comparison to the placebo group. Although not statistically significant, 42% of the participants who received the active intervention reported a successful outcome compared to 30% of the placebo group. However, 22 weeks later, the active intervention group showed a significantly greater improvement in shoulder pain and disability index than the placebo group $p<0.001$. Results revealed a 91% and 93% attendance rate to all sessions throughout the study however participants were only required to attend for 10 sessions which could explain why there was not a greater effect of the manual therapy intervention. Additionally, although the placebo group were not instructed to perform any specific exercises, they may have performed them of their own accord. Similarly, the results rely on adherence of the home exercises. Results from this study reveal that the addition of manual therapy may have greater long term benefits in pain reduction and mobility rather than short.

Unlike Bennell *et al.* (2010), results were more definitive by Bang and Deyle (2000) whereby they compared supervised exercises with and without the addition of manual therapy on patients with shoulder impingement syndrome. The manual therapy treatment provided consisted of passive accessory or passive physiological mobilisations, and the exercises provided to both groups were standard flexibility and strengthening exercises. Post hoc pairwise comparisons revealed a significant reduction in pain of 70% and 35% in the manual therapy group and exercise only group respectively, with the manual therapy group identifying significantly less pain ($p<0.05$). Additionally, the manual therapy group exhibited significantly greater improvements in regards to functionality and post treatment strength compared to the exercise only group. Therefore, results of this study concluded that supervised shoulder exercises combined with manual therapy were superior to exercise only in the improvement of pain, functionality and strength in people with shoulder impingement. These results are reflective of both participant and tester blinding which consequently enhances the reliability of the study.

Cleland *et al.* (2013) and Anderson *et al.* (2003) both investigated the effectiveness of ankle manipulations for the management of ankle sprains. Cleland *et al.* (2013) discovered the addition of manual therapy techniques significantly improved both pain and function in comparison to home exercise alone. However, Anderson *et al.* (2003) did not find a significant difference with the addition of manual therapy techniques in ankle range of movement. Despite this, the overall findings have a positive outcome in regards to improving pain and function, thus supporting the benefits of manual therapy. Whilst not directly comparable due to different methodologies and outcome measures, the conflicting results support the inconsistencies found within the research.

There is also an abundance of systematic reviews conducted to evaluate the effect various manual therapy techniques have on shoulder (Steuri *et al.,* 2017; Camarinos and Marinko, 2009) knee (salamh *et al.,* 2017) ankle (Fraser *et al.,* 2018; Doherty *et al.,* 2017) neck (Hidalgo *et al.,* 2017) and back injuries (Fredin and Lorås, 2017). The outcomes of these reviews are differing, however the generalised suggestion is that there is a beneficial and positive use of manual therapy in at least one outcome measure even if this is only minimal.

In a recent systematic review of treatment options for musculoskeletal pain, the effectiveness of manipulations, mobilisations and massage were found to be beneficial in the treatment of neck, back and shoulder pain and function (Babatunde *et al.,* 2017). Despite this, the authors conclude that the overall strength of the evidence is limited with small effect sizes likely because of heterogeneity across the clinical trials. Likewise, a systematic review conducted by Bonfort *et al.* (2010) reveals the effectiveness of manual therapy techniques to be ambiguous. The authors found that amongst 70 Randomly Controlled Trials, spinal manipulation was found to be superior to that of sham intervention in the treatment of low back pain, however research was inconclusive into the effects on sciatica. The authors also present limited and inconclusive evidence for the treatment of certain shoulder, hip and knee injuries but supportive evidence for others.

Steuri *et al.* (2017) also conducted a systematic review however investigating different conservative management techniques of shoulder impingement. Like the Babatude *et al. (*2017) review, they found conflicting results amongst the literature. Steuri *et al.* (2017) found that for the management of pain, manual therapy was superior to placebo (4 studies, n=137, SMD −0.35, 95% CI −0.69 to −0.01), manual therapy had an immediate effect following one session in comparison to a sham treatment (3 studies, n=134, SMD −0.62, 95% CI −0.97 to −0.28) and manual therapy plus exercise was superior to exercise alone (9 studies, n=363, SMD −0.32, 95% CI −0.62 to −0.01). Regarding functionality, the authors also report that manual therapy plus exercise was superior to exercise alone (7 studies, n=301, SMD −0.41, 95% CI −0.71 to −0.11). The results of this review suggest the inclusion of manual therapy to be beneficial to the management of shoulder impingement.

It is important to note certain limitations amongst systematic reviews within this area that need to be considered, such as publication bias and selective reporting. Both of which can lead to an over or under estimation of the effect of the intervention (Guyatt *et al.,* 2011). Clinical diversity and subject differences can also be accountable for contradictory results, with treatments affecting some differently to others (Foster *et al.,* 2009). One of the most important considerations when reviewing the literature should be the constitution of treatment efficacy. This will vary between both subjects themselves and research. Efficacy could be the return of full ROM in some studies, however minimising medication and returning to work for another. Thus, highlighting the difficulty in comparing multiple randomly controlled trials.

Although research into the effectiveness of manual therapy techniques on musculoskeletal pain and dysfunction is inconclusive, evidence does exist supporting some form of beneficial effect on pain and functionality albeit this outcome may not always be superior to other treatments and is not always unanimous amongst researchers.

4.5 Friction and Manual Therapy

Efficient stabilisation is essential when performing effective joint mobilisation (Vicenzino *et al.,* 2011). In order to achieve this, friction is required to prevent a loss of control, consequently leading to ineffective treatment. Wise, (2015) recommends two mediums in order to achieve this however this is not supported by evidence. Whilst more friction is needed with this technique, less is required when applying effleurage. This is because this form of massage requires the practitioner to glide over the skin of the client. An excess of friction here increases the likelihood of skin irritation and ineffective coverage of the body. The application of petrissage requires the hands to glide, whilst simultaneously applying a greater force than effleurage in order to affect the deep tissues. Therefore enough friction is required that force can be applied without skin irritation.

5. Manual Therapy Products

Review of Literature

Manual therapists will select treatment products based on the desired needs of the client. This includes manual therapy products in the form of oils, lotions, waxes and powders. As well as tools in the form of mobilisation belts and instrument assisted massage (Parsons, 2004). Some of these products are utilised with the intention to alter the coefficient of friction such as the mediums. Whereas other products do not have the intention to alter the value, but the coefficient of friction itself is important whilst using the appliance in creating effective treatment. For example, a greater frictional force is needed when using a mobilisation belt to prevent it from sliding therefore an increase in the coefficient of friction is needed. The scraper needs to be able to produce some degree of friction without being too much to still allow it to glide across the client.

If a small amount of friction is required, this needs to be achieved with as little skin irritation or deformation as possible (Hendriks and Franklin, 2010). Little to no scientific research exists regarding the effect of manual therapy mediums on coefficient of friction. Instead, products are usually selected based on client or practitioner preference, cost effectiveness or suggestive effectiveness. For example, oil is proposed to be less viscous in comparison to powders so has a lower coefficient of friction, therefore is stated to be more effective for treatments requiring less friction (Martin, 2007). Conversely, powders are stated to have a low glide coefficient so are best suited for deep tissue treatments (Casanelia and Stelfox 2009). Similarly, variations of the same products state different viscous properties and thus different coefficients of friction.

According to Woolstenholmes (2010), mineral oils do not penetrate the skin deep enough so are ineffective for deep tissue massage, whereas talcum powder is beneficial for grip and deeper massage. Similarly, Goldberg (2001) suggests that talcum powder is beneficial for the use of deep mobilisation. Whilst this may be accurate, there does not appear to be any form of research, testing or evidence provided to substantiate these claims. Despite this, practitioners can be found advertising their products based on this unsupported-evidence.

Although not discussing manual therapy mediums directly, research does exist regarding the coefficient of friction of other lubricants that are similar to those used in manual therapy. Ramalho *et al.* (2007) found that the application of glycerine and petrolatum to the forearm caused an immediate decrease in the coefficient of friction compared to the pre-treatment value. However, an increase in time was noted. After 15 and 45 minutes of the application of petrolatum and glycerine respectively, the coefficient increased to a larger value than before the treatment. This research could provide evidence for the use of Vaseline-type products within manual therapy and suggests if low frictional force is desired, then treatment should commence immediately. If, however, a higher amount or friction is required and this product is the best or only option, then treatment should commence following a period of time after application.

Research has also been conducted on the effects cosmetic cream has on the coefficient of friction on the finger pad (Gaikwad *et al.,* 2010; Sivamani *et al*., 2003). Tests were conducted in vivo on the dorsal finger in the study by Sivamani *et al.* (2003) whereby they monitored load and acceleration to maintain consistency. Whereas Gaikwad *et al.* (2010) used the corneocytes of the inner forearm via tape stripping. Whilst it has its benefits of being non-invasive, it is limited to the stratum corneum and is composed of mainly dead cells and so cannot be used for a broader analysis of skin. Despite different methods utilised, both studies discovered an increase in the coefficient of friction following the application of moisturising creams. However, Sivamani *et al.* (2003) also identified a change in the coefficient of friction when the normal load was increased from 5g to 45g subsequently supporting previous research and suggesting that Amonton's law may not be applicable with the skin's surface (Koudine *et al.,* 2000). This theory is further supported by studies of similar methodologies. It's also worth noting, that although these studies highlight that mediums alter the coefficient of friction, Sivamani *et al.,* (2003) only had four participants and Kaikwad *et al.,* (2010) only had five participants, thus the results cannot be generalised to a wider population. As aforementioned, variability between participants is high, therefore results would have been more reliable with a larger test size.

The application of creams has also been reported to decrease the coefficient of friction. Bernatchez *et al*. (2015) compared the coefficient of friction of skin against fabric when the skin was covered with either a silicone dressing or cream. The application of cream was found to significantly reduce the coefficient of skin against the fabric by 32.8% ($p < 0.001$). This is of importance to healthcare professionals as this can help to reduce decubitus-related sores and injuries. However, it is also of significance to manual therapists to prevent friction-related injuries. For example, to aid with the prevention of chaffing from the contact of skin and clothing in many athletes, as well as providing evidence that an excess of friction may not be warranted with certain techniques.

Creams are not the only mediums reported in the literature to increase the coefficient of friction. Carré *et al*. (2012) applied Powdered and Liquid Chalk, Rosin and Venice Turpentine to the finger of a rock climber and tested the coefficient of friction between a steel surface and a sandstone surface using a finger rig method. The application of venice turpentine to the steel surface was shown to increase the coefficient of friction. However, both chalks and the rosin decreased the coefficient. Remarkably, no significant difference was noted on sandstone surface. The authors attribute this to the absorptive properties of the sandstone. Nevertheless, this highlights the effect surface has on the coefficient of friction. The difference between testing surfaces highlights the need to consider the testing surface in tribological studies in order to compare to previous and future research.

Despite this finding, Amca *et al*. (2012) also studied the effect chalk had on the coefficient of friction of climbers' fingers and climbing holds between two different surfaces. Unlike Carré *et al*. (2012), the application of chalk lead to a mean increase of 18.4% in the coefficient of friction for both surfaces. Although the increase occurred for both tested surfaces a significant difference was seen between the two surfaces thus supporting Carré *et al*. (2012).

Although it is established that the application of different mediums alters the coefficient of friction, limited research exists comparing the different types of mediums in a single study. This consequently means the coefficient of friction values are not relative as test conditions differ between studies. The research does allow practitioners to have an awareness of what mediums increase and decrease friction but the extent of this cannot be concluded. Furthermore, previous research into this area has looked into the coefficient of friction of cosmetic products therefore these studies cannot be entirely representative of manual therapy mediums.

6. Methods

6.1 Stage 1 – Preliminary Testing- Initial Set-Up

The tests were performed in a controlled setting with a constant temperature (24–26°C).

The preliminary test set-up consisted of a force-acceleration sensor (PS-3202, PASCO, USA) screwed onto a scientific testing carriage (ME-9454, PASCO, USA) (Appendix 1.1) and connected to a personal laptop via a standard connecting wire. Braided physics string (PASCO, USA) (Appendix 1.2) connected one end of the testing carriage to a calibration weight (Appendix 1.3). The string used was produced and consequently chosen due to its non-extensible properties. This allowed the sliding velocity to remain constant across all tests by preventing unwanted transfer of kinetic energy from the motor to elastic potential energy in the string. The string also allowed for standardisation of its length throughout testing. The same string was also connected to the other end of the carriage and connected to a battery powered motor (appendix 1.4). The motor was clamped to the table by two one-inch mini spring clamps. Both the scientific testing carriage and the calibration weight were pulled back until the sting was taut. A full schematic of the testing apparatus is Shown in Figure 4.

To begin, the battery pack was switched on which caused the attached string to ravel inwards pulling the scientific testing carriage across the table and the interchangeable weight across a levelled piece of acrylic. Once the end range had been reached, the string was unwound and returned to the same initial starting position. This process was repeated 30 times. The force and acceleration data were simultaneously transmitted to PASCO Capstone Software via the attached wire from the force-acceleration sensor to the laptop.

The results of this testing can be found in section 7.1, table 3.

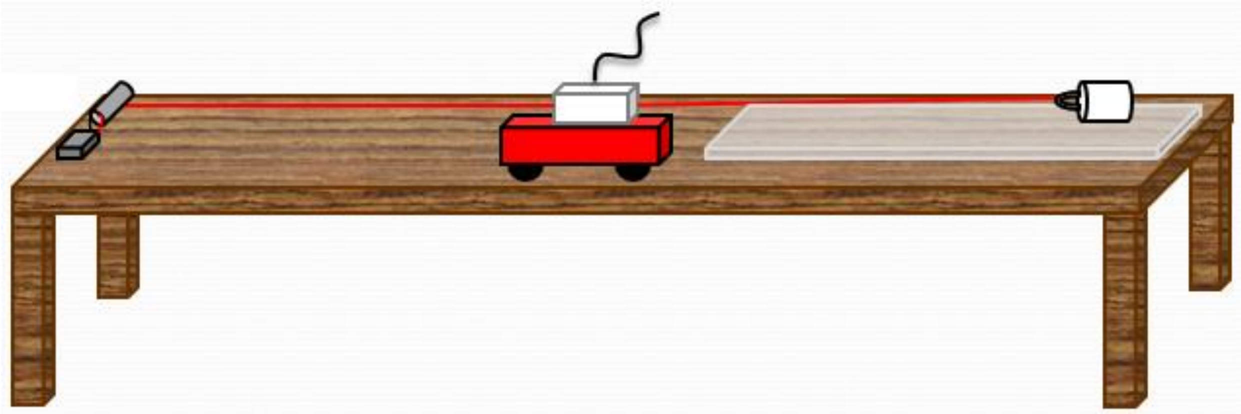

Figure 4. Schematic diagram of preliminary testing apparatus

6.1.1 Stage 1 – Preliminary Testing – Adaptation 1

The battery powered motor proved to be inconsistent as evidenced in section 7.1, likely a result of progressive depletion of the batteries until they were eventually flat. This caused inconsistencies in sliding velocity which was evidenced as the scientific testing carriage would “judder”. This ultimately affected the acceleration and consequently the force of friction.

The battery powered motor was replaced with a rotational motor drive (ME-8955, PASCO, USA) and was fixated to a vertical shaft with pulley on a rotating platform (PASCO, USA) (appendix 1.5). This was powered by a DC Programmable Power Supply (PI-9880, PASCO, USA) (appendix 1.6) which unlike the battery powered motor, allowed for a constant velocity to be set by altering the voltage output.

The set-up was like that of the initial set-up, except the string was now wound around the rotational motor drive instead of the battery-operated motor. The carriage and calibration weight were pulled back until the string was taut and the power supply was set to 5V. The start button was pushed causing power to be sent to the motor. This in turn caused the rotating platform to wind the string in and consequently pull the carriage and the calibration weight. As before, this was repeated 30 times.

The results of this testing can be found in section 7.1, table 3.

6.1.2 Stage 1 – Preliminary Testing – Adaptation 2

During the above test set-up, lateral movement of both the scientific testing carriage and the calibration weight were noted. This noticeably affected the acceleration which ultimately impacted the force of friction. These lateral movements were due to the connective wire from the laptop was pulling on the scientific testing carriage and the cylindrical shape of the calibration weight. These inconsistencies were rectified by replacing the wire with a wireless Bluetooth™ sensor and by substituting the calibration weight with a plastic rectangular based tray (Appendix 1.7). The tray was measured at 0.008m^2 and allowed for interchangeable calibration weights to be placed within and padded with a standardised amount of cotton wool to prevent unwanted movement. The absence of the cotton wool would have allowed the weight to move creating an uneven weight distribution within the tray allowing for potential disturbances to the force. Prior to use, the combined weight measurement was taken. These corrections allowed for linear movement.

The results of this testing can be found in section 7.1, table 3.

6.1.3 Stage 1 – Preliminary Testing – Adaptation 3

The application of the manual therapy mediums onto the acrylic was trialled however proved unsuccessful as the mediums dispersed unevenly across the acrylic and over the edge. Therefore, a computer numerical control router was utilised to cut a rectangular hole within the acrylic. This would allow for the mediums to be placed within and prevented from seeping over the edge whilst also maintaining a levelled layer. Despite this adaptation, and numerous attempts at sanding the new acrylic, results showed that that average coefficient of friction of the new acrylic was higher and was more varied as evidenced in section 7.1, table 3.

Therefore, instead of cutting a hole out of the acrylic, a border was created and glued onto a new piece of acrylic thus creating the same affect whilst also maintaining surface smoothness.

The three adaptations from the preliminary test set-up allowed for the final experimental test set-up and A full schematic of the testing apparatus is Shown in Figure 5.

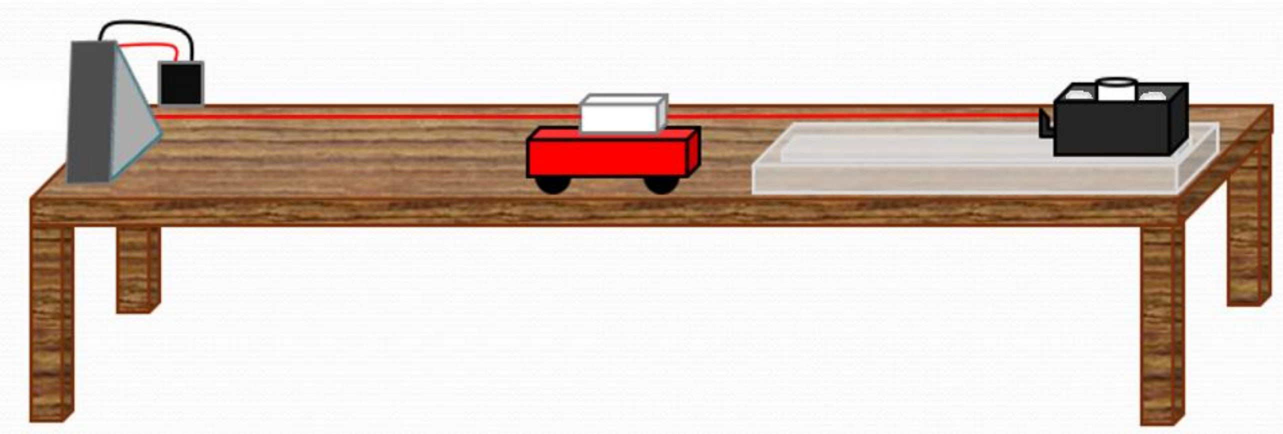

Figure 5. Schematic diagram of final testing apparatus

6.2 Stage 2 – Set-Up Validation

Validating the set-up and distinguishing the most consistent method was the following stage. Assembly of the equipment was as outlined in the 'Preliminary Testing – Adaptation 3'. Initially, the combined weight of the tray, calibration weight and cotton wool were 247.5g and the DC programmable power supply was set to a constant velocity of 5v with a speed of 0.51m/s. Both the carriage and tray were pulled back until the tray was at the beginning of the acrylic and both pieces of string were taut. The power supply was then switched on causing the motor to turn the rotating platform clockwise and wind in the string, consequently pulling the carriage and tray across the acrylic at a constant rate. The force and acceleration data were simultaneously transmitted to the laptop via the wireless Bluetooth™ sensor to PASCO Capstone software whereby force acceleration graph was shown and then data exported and saved to excel to determine the coefficient of friction. Once it reached the end range, the string was unwound and returned to the same initial starting position. This process was repeated 10 times to reduce the risk of error and thus increasing reliability.

On completion of this, the same process was repeated except the combined weight was changed to 395g and then 500g still at 5V. The same process was repeated again but with a combined weight of 500g at 5.5V to establish the most reliable and consistent testing method. Although the main purpose of changing the variables was to establish which data provided the least variability, it also allowed us to inadvertently test the other laws of friction regarding load and sliding velocity.

The results of this can be found in section 7.2.

6.3 Stage 3 – Artificial Skin Validation

The test set-up was as described above but with the inclusion of three pieces of artificial skin clamped to the acrylic. Despite the use of speed clamps to prevent unwarranted movement, ripples within the acrylic prevented movement of the tray and the force and acceleration was unable to be accurately obtained. More clamps were acquired however despite best efforts, the ripples still occurred and consequently prevented the tray in moving. Furthermore, several brands of artificial skin were purchased each with a thin layer of a powdered substance covering the surface which impacted the force of friction during testing. Due to the sensitivity of data collection, the artificial skin was deemed to be an unreliable testing material. Therefore, testing of manual therapy mediums were performed on the acrylic.

6.4 Stage 4 – Testing of Manual Therapy Products

Once proven to be reliable, the same set up as above with the 247.5g load and subsequent base pressure of 303.75 Pa was utilised to test the manual therapy products. Three different forms of mediums were used, each with three different manufacturers. They were as follows: Oil (Grapeseed, Olive, Schupp), Cream (Baselin, Mueller®, Rubbeez®) and Wax (Annie's, RockRub, Songbird®). A full list of ingredients can be found in Appendix 2.1. To standardise the tests, 10g of each medium were weighed, applied and spread manually with a silicone spatula across its horizontal edge to allow for it to be equally levelled with only a thin layer of medium. For each medium, the test took place 30 times to reduce the risk of error and thus increasing reliability. After each run through, the medium was re-spread to ensure even and consistent distribution.

6.5 Data Processing

A Bluetooth™ enabled force sensor incorporating a triaxial accelerometer (PASCO, USA) assessed both force and acceleration and sent data directly to a laptop. Capstone software (PASCO, USA) (sampling frequency: 20 times per second) was used to acquire data and displayed the data as force versus time. The outcomes of interest were static and dynamic coefficients of friction. This is evidenced in the graph from the Capstone Software (PASCO, USA) whereby the initial peak corresponds with the static coefficient and the remainder is the dynamic coefficient of friction (Figure

5). The coefficient of friction was defined as the ratio of force of friction to the normal force, μ = F / N. Data will be processed and presented on a spreadsheet on Microsoft Excel (version 15.0, Microsoft, USA).

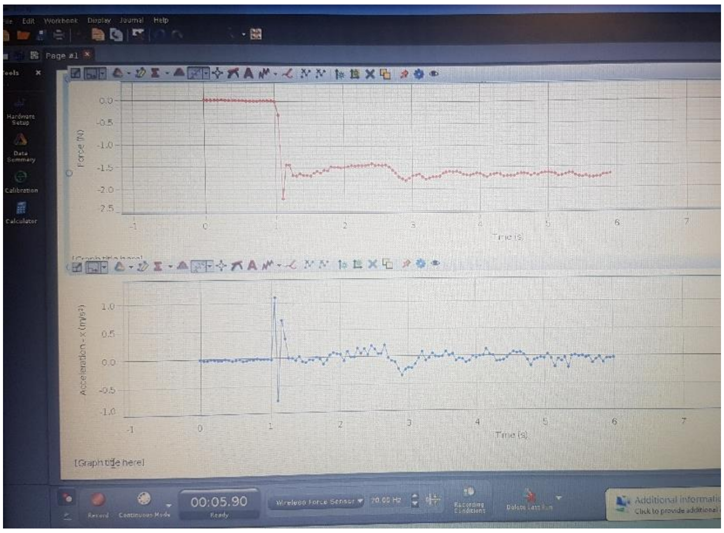

Figure 5. Data from Capstone Software (PASCO, USA) highlighting static peak and dynamic portion

6.6 Statistical Analysis

Statistical analyses were performed using SPSS v.14.01 (SPSS, Inc., Chicago, IL, USA). The assumption of normality was violated therefore bootstrapped means and confidence intervals were used (Kelley, 2005). For all analyses, statistical significance was set at a probability value of $p<0.05$. All results will be presented as means and 95% Confidence Intervals.

7. Results

7.1 Preliminary Testing Results (Stage 1 - Adaptation1, 2 and 3)

The coefficient of variation was calculated for each test-set up to analyse the spread of the data and to establish the most consistent testing method. Table 3 shows the mean coefficient of friction, standard deviation and coefficient of variation for the preliminary testing, the first adaptation with the replacement motor, the second adaptation with the wireless connection and the tray and the third adaptation with the new acrylic.

Table 3. Mean Coefficient of Friction (CoF), Standard Deviation (STD) and Coefficient of Variation (COV) values of the preliminary test set-ups

	Preliminary Testing	Adaptation 1 *Motor*	Adaptation 2 *Wireless & Tray*	Adaptation 3 *Acrylic*
Mean CoF	0.05	0.07	0.26	0.28
STD	0.02	0.02	0.03	0.06
COV %	37.63	25.53	13.19	21.27

Results from Table 3 show the original test set-up demonstrated a variation within the data spread of 37.63%. This variation reduced to 25.53% with the replacement of an electric motor and the allowance of constant velocity. This further reduced to 13.19% with the inclusion of a wireless force-acceleration sensor and a flat-based tray. The replacement of the acrylic for one with the routed hole however increased both the coefficient of friction value and the coefficient of variation to 0.28 and 21.27% respectively.

7.2 Test Set-up Validation Results (Stage 2)

Table 4 shows the mean coefficient of friction, standard deviation and coefficient of variation values for the validation results on the testing of the replacement acrylic with different loads and sliding velocities.

Table 4. Mean Coefficient of Friction (CoF), Standard Deviation (STD) and Coefficient of Variation (COV) values of the validation set-up

	Set-Up Validation - *New Acrylic*			
	247.5g 5v	**395g 5v**	**500g 5v**	**500g 5.5v**
Mean CoF	0.15	0.17	0.19	0.22
STD	0.02	0.04	0.03	0.04
COV %	16	24	17	17

Results show that with the addition of the replacement acrylic, the variation declined once again as evidenced in Table 4. Changing the load and voltage output impacted both the coefficient of friction and coefficient of variation values. The lowest variation was demonstrated with the load of 247.5g at 5v which subsequently became the final testing method when testing the manual therapy mediums.

7.3 Effect of Load and Sliding Velocity

The assumption of normality was met p=0.729 therefore a one-way analysis of variance (ANOVA) was performed to determine whether a statistically significant difference existed between baseline measurements of differing loads and sliding velocities.

There was no statistically significant difference found between the 247.5g load and the 395g load (p=1.000) or the 500g load (p=0.456). There was also no statistically significant difference between sliding velocities at 5V and 5.5V (p=0.222).

7.4 Effect of Medium

The assumption of normality was violated when assessing for an effect of manual therapy medium on the coefficient of friction on some of the mediums (Mueller® Cream p=0.00, Rubbeez® Cream p=0.04, Olive Oil p=0.00, Annie's Wax p=0.00), therefore a bootstrapped version of statistical tests were used.

A one-way between subjects ANOVA was conducted to compare the effect of manual therapy mediums in the form of creams, oils and waxes on the dynamic coefficient of friction. A stastically significant difference was found between the different mediums (F (2,267) =34.807, p=0.00).

Post hoc comparison using the Bonferroni test indicated that the mean dynamic coefficient of friction for wax was 0.30 (95% CI, 0.26 - 0.35). This was significantly different from cream 0.16 (95% CI, 0.13 - 0.19) p=0.000 and oil 0.09 (95% CI, 0.07 - 0.12) p=000. There was also a statistically significant difference between cream and oil p=0.037. These results suggest that manual therapy mediums effect the coefficient of friction with oil producing the lowest and wax producing the highest coefficient of frictions respectively (Figure 6). With 21% of the total variance being accounted for by the medium.

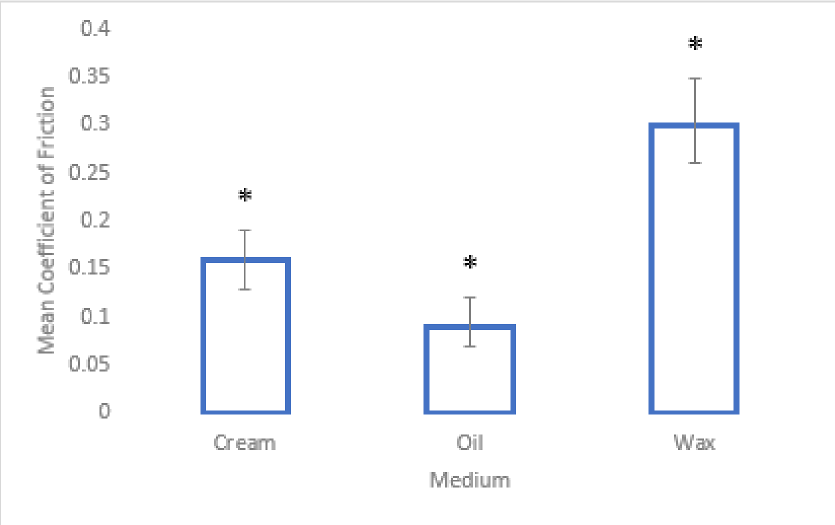

Figure 6. Bootstrapped Mean coefficient of friction values and 95% Confidence Intervals for mediums. Significant differences between mediums are shown in the figure * $p < 0.05$

Post hoc comparison using the Bonferroni test also indicated differences between the mediums and baseline measurements. The mean dynamic coefficient of friction for the baseline measurement was 0.15. The wax significantly increased the coefficient of friction from the baseline with a mean difference of 0.14 (95% CI, 0.09 – 0.20) (p=0.039). The mean difference from the baseline for the cream and oil were 0.01 (95% CI, 0.03 – 0.06) and -0.05 (95% CI, 0.01 – 0.09) respectively (p=0.01).

7.5 Effect of Manufacturer

Magnitude based inferences reveal differences and confidence intervals between the tested brands (Figure 7).

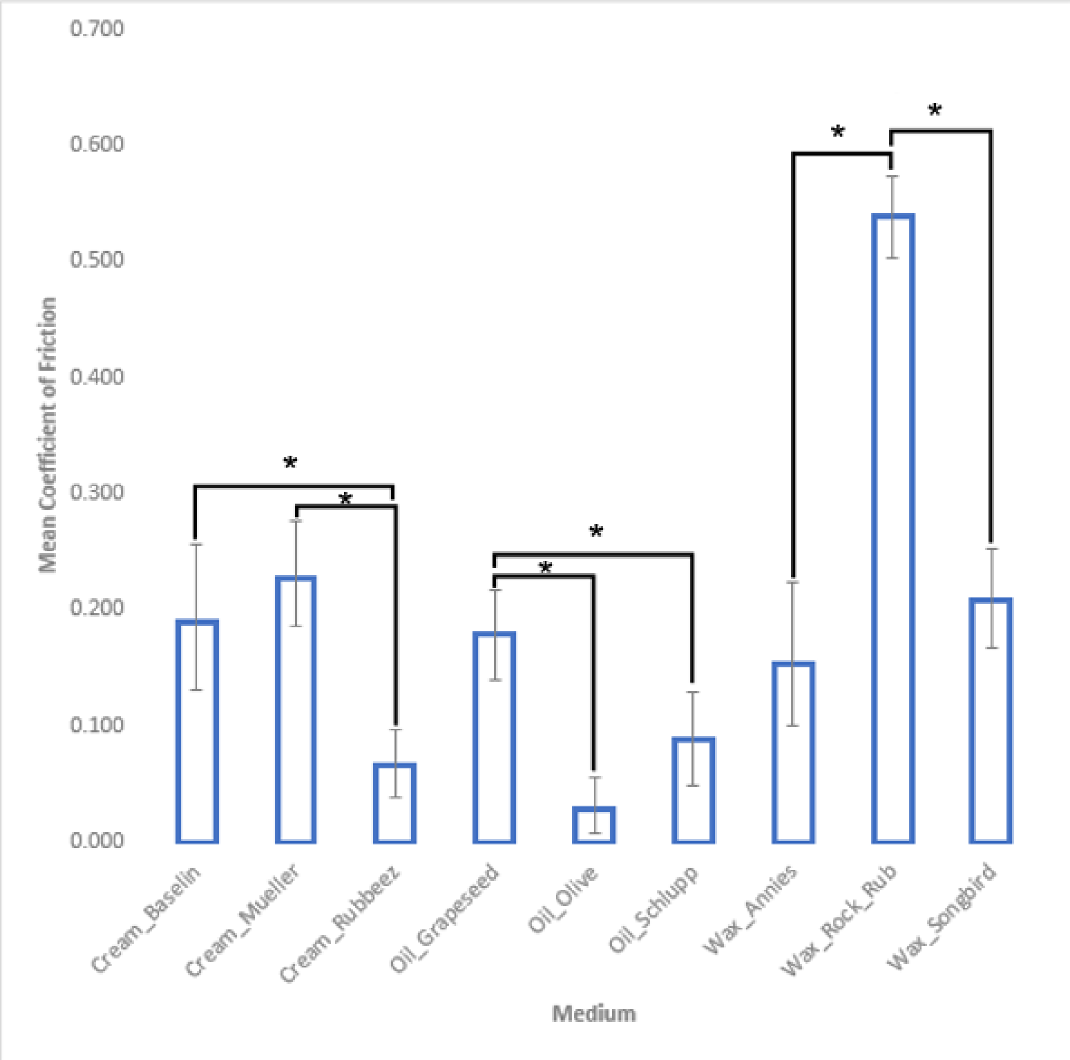

Figure 7. Bootstrapped Mean coefficient of friction values and 95% Confidence Intervals for all tested brands as magnitude-based inferences. Significant differences between brands are shown in the figure * p < 0.05

A one-way ANOVA was performed on the individual medium brands to determine whether there was a statistically significant difference in coefficient of friction. The coefficient of friction for the Rubbeez® cream was significantly lower than the Baselin and Mueller® creams with a mean difference of 0.12 (95% CI, 0.06 to 0.20) and 0.16 (95% CI, 0.11 to 0.22) respectively.

The coefficient of friction for the Grapeseed oil was significantly higher by 0.15 (95% CI, 0.10 to 0.12) than the Olive oil and significantly higher by 0.09 (95% CI, 0.03 to 0.15) than the Schupp oil.

The coefficient of friction for the RockRub© wax was significantly higher than the Annie's wax and Songbird® wax with a mean difference of 0.38 (95% CI, 0.30 to 0.45) and 0.33 (95% CI, 0.27 and 0.38) respectively.

8. Discussion

Friction measurements can provide a quantative insight into the effects of different manual therapy mediums. Most evidence surrounding manual therapy products are based upon opinion rather than quantified in research. Similarly, numerous studies have demonstrated the effects of various lubricants however insufficient evidence exists comparing these mediums within the same research or specifically as manual therapy mediums. The present study was designed to determine whether manual therapy mediums alter the degree of friction, and whether different manufacturing brands differ significantly amongst each other.

As expected and the same as previous research, the static coefficient of friction values for the control testing and medium testing were higher than the dynamic coefficient of friction values, satisfying the conditions of Coulomb's law of friction (Trømborg *et al*., 2011; Rabinowicz, 1951). It is necessary to obtain these values to evaluate any changes caused by the applied mediums.

Previous research has found the force of friction to be directly proportional to load (Pitenis *et al.,* 2014; Jiang *et al.,* 2008; Yifu *et al.,* 2017). The results from the present study were in agreement with this however the results were not of any significance. Opposing this, Chowdhury *et al.* (2012) found as load increased, the friction force decreased which conflicts with Amonton's first law of friction. Popova & Popov (2015) state this could be because Amonton's first law is outdated and limited in scope, only valid to hard surface materials such as woods, plastics and metals. This is supported by Bostan *et al.* (2016) who state that this is due to the elasticity of skin. As load increases, there are increases in elasticity and deformation which in turn increases contact area, potentially decreasing coefficient of friction. Skin behaves differently under load to acrylic; therefore, this is a potential limitation to the validation of the current study. Similarly, previous studies have assessed the difference in greater load ranges whereas in the present study the load range was quite similar so could offer a reason as to why no significant was seen in regard to load.

Based on the findings of previous research, if an increase in friction is the requirement, more pressure may need to be applied to achieve the desired effect Tomlinson *et al.* (2009). This is another example of Amonton's first law of friction. Therefore, the practitioner may need to lower the couch or adjust the body position in order to achieve this.

Previous research has found dynamic friction to be independent of sliding velocity (Chowdhury *et al.,* 2012). Although in this study, coefficient of friction values increased as sliding velocity increased, this was not of any significance. Conversely, Gunes (2005) found as sliding velocity increased, the coefficient of friction decreased.

The results obtained in this experiment are comparable to a number of studies in this field (Bobjer *et al.,* 1993; Hendriks and Franklin, 2010). The vast range of measurements obtained may be attributed to varying tribological methodologies. Many factors can affect the outcome of results in tribometry, such as skin, the current cleanliness of the skin, number of participants, frictional motion, equipment and the body area or material tested (Derler and Gerhardt, 2012).

It is important to consider the dryness and cleanliness of the skin prior to testing. Many studies have concluded that wet skin, whether through sweating or the manual application of water, produces a greater coefficient of friction than dry skin (Johnson *et al.*, 1993; Masen, 2011; Adams *et al.*, 2007). This is important knowledge in a manual therapy setting, as clients are usually dried prior to treatment. On the other hand, there is no research exploring the coefficient of frictional changes of acrylic when wet, so it is unclear if there is any effect. However, it has been shown that the application of water can reduce the coefficient of friction in other materials such as vinyl composite tiles (Hanson *et al.,* 1999). Because the application of water has been shown to affect the coefficient of friction of materials, it was important to ensure the dryness of the acrylic to obtain reliable results. The present research did not investigate the effects of water on the coefficient of friction, however some of the mediums used were water-based. Therefore, when observing the results from this study, it can be assumed that the application of water to the acrylic would have made an effect on the coefficient of friction.

The current study utilised a linear sliding method via an accelerometer to record acceleration to calculate coefficient of friction. This testing method was like that of Gratton and Defrancesco (2006). The coefficient of friction values obtained from their testing of wood on plastic surface was

0.174±0.003 and wood on paper was 0.18±0.03 which is comparable to our baseline testing on the acrylic which was 0.15. Despite the similar results, Gratton and Defrancesco (2006) set-up methods displayed their force sensor connected via a wire to a laptop. The wire could have caused unwanted lateral movement which ultimately could have impeded their force of friction values, something which this study attempted to eliminate by using a wireless force sensor. 'Pin on disc' tribometers seem to be most common tool used to record the coefficient of friction of a material. This involves a fixed probe under an applied load in contact with a rotating disc. This is a very effective method in adapting loads and sliding velocities. In comparison to Gratton and Defrancesco (2006) and the present study, the machinery used within pin on disc methods allows for more controlled testing parameters. Whilst pin on disc can be considered 'gold standard' of measuring friction, the contact area available to test is quite limited and it is only useful on inanimate materials and not possible to perform on a live participant. Although this method is applicable to acrylic, the mediums tested in this study are intended for use in a manual therapy setting, therefore a sliding method can be deemed more valid. Aside from frictions, other massage strokes primarily involve firm sliding pressure applied in a singular direction (Vickers and Zollman, 1999) and this may be a reason why many prior studies have utilised this methodology (Nakajima and Harasaka 1993; Li *et al.*, 2006; Sivimani *et al.,* 2003).

It could be assumed that the results obtained in this study are not entirely valid when applied to a sports therapy environment, due to data collection taking place on acrylic rather than real or synthetic skin. On the other hand, the acrylic has less confounding variables in comparison to skin thus can be utilised as a benchmark on which future skin studies can build from. The use of a participant's skin can greatly decrease the reliability of the study. This is due to the many parameters such as hydration, temperature and occlusive materials on the skin surface affecting skin friction (Highley *et al.,* 1997), making it difficult to recreate in additional studies. Conversely, Gitis and Sivamani (2004) produced a literature review that both supports and opposes the aforementioned statement. Whilst the review agrees that there are many factors that simultaneously affect the coefficient of skin friction, there is little variation in the friction coefficient of volar forearm skin despite the parameters. This would suggest that to increase external validity, future adaptations of this study should attempt to measure change in friction due to an external medium using the volar forearm. However, this may not be the case as there is not any other research that has come to the same conclusion. Furthermore, the coefficient of friction measured via the volar forearm can differ greatly between studies. An example of this can be noticed when observing the work of Elleuch *et al.* (2006) and Kwiatkowska *et al.* (2009). Both studies utilised a spherical steel probe to slide upon dry volar forearm skin to obtain the skins coefficient of friction measurements (Table 2). The vast difference between the results suggests that there is great variation in skin roughness between humans, with no definitive measurement to be used as a baseline. This indicates that skin may not be as valid as first presumed. This also applies to synthetic skin, which is intended to imitate real skin. Therefore acrylic can be deemed as an appropriate testing surface as it seems more reliable and the friction coefficient of the acrylic in a dry situation is within the range of the friction coefficient of skin obtained by Ramalho *et al.* (2007) and Egawa *et al.* (2002), (shown in Table 2).

Although not statistically significant (p=1.00), the application of oil onto the acrylic surface caused a decrease in the coefficient of friction by 40%. Despite the use of human skin as opposed to acrylic, Highley *et al.* (1977) obtained similar results. They also found a gradual increase in the coefficient of friction following the initial decrease when excess oil was removed from the frictionmeter after each test run for up to 15 minutes. This is likely due to the oil acting as a barrier. This could indicate if manual therapy treatment were to continue for longer than this period and excess oil was spread over a large surface area, re-application may need to be made to ensure efficacy. Glycerine is often utilised within cosmetics due to its hydrating qualities and properties as a natural oil (Lodén and Maibach, 1999). Ramalho *et al.* (2007) tested the effects of glycerine on the coefficient of friction and found it created a decrease in friction for approximately 30 minutes after initial application on the ventral forearm and 60 mins on the palm of the hand. The coefficient of friction measurements five minutes following application ranged approximately between 0.5-0.6 which is substantially higher than the values reported from this study of 0.09.

Unlike the oil, the application of cream produced an increase in the coefficient of friction although again, this was not of any significance (p=1.00). This is dissimilar to previous findings whereby the application of cream lead to a decrease in the coefficient of friction (Macedo *et al.,* 2012; Skedung *et al.,* 2016). The findings of the present study could be as a result of the linear movement during testing, causing an accumulation of cream at the front of the sliding tray, subsequently acting as a barrier and creating a greater resistance to movement. Whereas the testing of Macedo *et al.* (2012) performed in a rotary motion making this accumulation less likely and acting more similarly to the effleurage motion of manual therapy. Despite this different response, the results from this study produced an average coefficient of friction value of 0.16 for cream proving similar to Macedo *et al.* *(*2012) whereby their friction value of cream was 0.15, although this is only representative of one brand whereas we compared three different brands. Opposing this, Skedung *et al.* (2016) and Tang & Bhushan (2010) both produced values for cream between 0.3-0.4 and 0.6-0.8 respectively which is considerably higher than the results of this study, however their testing took place on synthetic skin and rat skin respectively which could contribute to the increased friction results appose to the present study whereby acrylic was utilised and Silicone utilised for Macedo *et al.* (2012). Although displaying higher coefficient of friction values than the present study, Tang & Bhushan (2010) also found the application of cream increased the coefficient of friction rather than decreasing it. They also found cream film thickness to be proportional to an increase in coefficient of friction perhaps signifying that their values are obtained based on a thicker film than the present study. Cream thickness could have contributed to the results of Skedung *et al.* (2016) as they tested on a small surface area that involved rubbing the finger back and forth repeatedly. It's possible, that the rubbing of the finger caused the film layer to dissipate and consequently the friction then becomes a result of the interaction between the finger and the model skin. Another possible reason for the high value is the model skin was soaked in water and glycerine prior to the testing to simulate hydration of real skin. It has been shown in previous studies that greater hydration increases the coefficient of friction of skin. (André *et al.,* 2011; Man *et al.,* 2009; Gerhardt *et al.,* 2008).

The application of wax in the present study caused a significant increase from the control measurement and had a coefficient of friction value of 0.30. Ramalho *et al.* (2007) tested the effects of petroleum jelly on the palm of the hand and ventral forearm. Although the same wax was not utilised, petroleum has a very similar consistency so was considered comparable. Results yielded a coefficient of friction value of 0.8 for both anatomical sites 5 minutes after application which was a decrease in friction from the standard control measurement. Interestingly, 15 minutes following the application to the forearm, the coefficient of friction values increased higher than the standards control measurement. Although the authors did not state whether this was of significance, this could have potential implications to manual therapy techniques, as often treatment commences immediately following application when perhaps it may be more beneficial to wait for a certain period of time. Although this is a reflection on real skin, the same affects were not seen with the palm of the hand indicating the effect anatomical location has on friction. Glaborus skin is situated on the palmo-plantar surface which may explain why is has differing friction properties to hair covered skin on the rest of the body. Furthermore, the glaborus skin possesses a thicker stratum corneum as a means to protect the underlying tissues from strong external forces and friction (Tagami, 2008). Additionally, only five assessments were made per test condition on only one participant which consequently makes this study underpowered and the true effect may not necessarily be inferred.

Results displayed a significant difference between oil, cream and wax indicating that as products they will provide differing degrees of friction, consequently supporting the necessity for a variety of different mediums within manual therapy. The wax had the significantly highest coefficient of friction whereas oil had the lowest.

These findings can be attributable to the viscosity of the mediums. Tang and Bhushan (2010) found an increase in dynamic viscosity lead to an increase in coefficient of friction when considering various skin agents. Although not directly looking at manual therapy mediums, similar products of similar consistencies to the ones in the present study were used. In their study, the pure lanolin used which is comparable to the wax used in this study presented with a higher coefficient of friction which has a higher viscosity than the aqueous glycerine and skin creams.

The data collected reaffirms common beliefs pertaining to the chosen mediums, that wax creates greater coefficient of friction. Wax caused a significant change when compared to the baseline measurement, therefore it can continue to be utilised in manual therapy for certain strokes that require a vast amount of friction to achieve the desired effect. However, even though cream and oils were significantly different to each other, both mediums did not cause a significant difference to the baseline measurement. Because of this, it is not possible to conclude that these mediums will aid a specific affect in manual therapy if the manual therapy technique requires an increase (or decrease) in friction with the skin.

It is possible that this result was achieved due to the sample sizes of each medium. By evaluating only three brands per medium it is difficult to notice any anomalies; therefore, it does not represent an accurate representation of the medium as a whole as there are a vast array of mediums available on the consumer market This reasoning can be explored further when comparing the differences between brands.

Despite the significant difference between mediums, results varied when formulating comparisons between brands. The Grapeseed oil was the only one significantly different in comparison to the other two. Similarly, both Rubbeez®™ and RockRub© were significantly different between the creams and waxes respectively. The effect of viscosity could provide an explanation for this outcome.

Lin (2013) tested the effects of three oils, each with different kinematic viscosities on the coefficient of friction. Results revealed an increase in the coefficient of friction as viscosities increased. This is further supported by Kim and Jeon (2008) who found the friction of oil was directly proportional to oil viscosity. However, Nacht *et al.* (1981) present slightly different findings. It was shown that various viscous lubricants such as petrolatum and heavy mineral oil decreased the coefficient of friction immediately after application to the skin. However, the lubricants were absorbed into the skin over time, thus gradually increasing the coefficient of friction. Therefore, it can be assumed that less viscous oils would provide increased lubrication to the skin, however further research on skin would be needed to confirm this. Similarly, Loden *et al. (*1991) found the same effect to be apparent with creams. The authors compared five different moisturising creams and found the cream with the highest viscosity displayed the highest coefficient of friction. Taking this into consideration, if the Rubbeez® cream demonstrated figures as low as some of the oil products, and had a potential viscosity like that as oils, then what quantifies it as a cream during its application in manual therapy.

The testing of the waxes could have evidenced the most obvious possibility of viscosity effecting the coefficient of friction. During testing, RockRub© was the only wax that maintained its consistency when being spread across the acrylic, whereas this appeared to reduce for the other two.

Coincidently, RockRub© displayed the significantly highest dynamic coefficient of friction value which was 0.54 whereas Annie's and Songbird® were significantly lower with 0.15 and 0.21 respectively. Both Annie's and Songbird® lost their consistency quickly resembling that of a thickened liquid. The difference in hardiness and consistency of wax can often be as a result of oil content (ASTM Committee D-2 on Petroleum Products and Lubricants, 1947). This could offer an explanation into the differences in consistencies with the tested waxes as both Annie's wax and the Songbird® wax had a smoother consistency and appeared to display more oils present within the ingredients in comparison to the RockRub©. Melting points could also offer potential reasoning as Speight (2015) found that waxes with containing a higher oil content are generally softer upon touch and often have a lower melting point. Therefore, if a wax with a higher coefficient of friction is desired, then it could be recommended to make use of one with a lower oil content. Similarly, Ekaputra *et al.* (2014) discovered that wax viscosity was inversely proportional to temperature. Although, the temperature remained consistent during this study, if waxes do have different melting points then the temperature of the room or the heat generated from spreading the waxes would affect them different and consequently effect the coefficient of friction. It would be beneficial for future studies to attain information prior to experimental procedure to be able to conclude if this is the case.

Unlike the aforementioned studies, although the viscosity of the mediums in the current study were not measured, it has been established that participants have the ability to evaluate the viscosity of mediums based on feel and that this correlated with instrumental measurement of friction (Loden *et al.,* 1991; Nacht *et al.,* 1981). During testing, it was evident from sense of touch, that the RockRub© was much more viscous than the other two waxes. This will also be clear to practitioners during the application of products. A more viscous wax will usually be beneficial for manual therapists, as wax is commonly utilised to increase the coefficient of friction.

The results show that if the intention of a technique were to increase friction, for example with the application of cross friction massage then wax is the most effective medium. Alternatively, during effleurage where less friction is required, oil will prove more efficient for the practitioner.

9. Conclusion

In conclusion, the results in this study can offer evidence for current practices within sports therapy by supporting assumptions previously made regarding the frictional differences of manual therapy mediums. The results were able to highlight significant differences between the dynamic coefficient of friction of oil, cream and wax, signifying the necessity for the vast variety or products within manual therapy. Initial findings coincide with traditional beliefs of frictional properties of each medium. This includes the use of wax to create friction for deeper strokes and the use of oil to decrease friction for shallow, softer strokes.

The research also demonstrated significant differences between brands of the same medium. As a result of this, it may be beneficial for consumers to be able to identify the effectiveness of each brand in regard to the coefficient of friction between them. This would be difficult to accomplish; however it could be possible to devise a rating scale to signify the degree of friction or quality of each brand in a similar vein to UK 'traffic light' food packaging (Sacks *et al.*, 2009). This would require extensive research into many brands of oils, creams and waxes in order to create the scale. This would need to include research into the individual ingredients of chosen mediums to explore the potential cause of these differences. The findings of this study can also be used as encouragement for future manufacturing of products intended to affect the coefficient of friction in a manual therapy setting. Not all the brands provided significant differences, perhaps this being attributable to the low sample size, as only three brands for each medium were analysed. Another confounding variable that may have impacted data collection could be the temperature of the room. Although this remained constant, the temperature may have been too high causing a change in the wax consistency and consequently the overall coefficient of friction. Perhaps, had the room been slightly cooler, results may have differed. Similarly, accumulation of medium in front of the tray was a difficulty to maintain which may have influenced higher coefficient of friction results. Future research could be more effective by developing a rig to allow for consistent application of the mediums.

It has been established that monitoring sliding velocity and load is important, which allowed for this current research to provide reliable data collection. Similarly, previous research has identified numerous confounding variables with skin, which allowed the baseline testing on acrylic within this study to be of benefit. However, it has been recognised this has limitations as unlike the acrylic, the skin's surface is not completely flat. In addition to this, skin is porous and would potentially absorb the mediums into the stratum corneum. Therefore the findings of this study are only applicable to the mediums that would leave a surface layer on the skin, as this would be an accurate representation of lubrication on the skin. Furthermore, for this to be truly representable of true manual therapy techniques future research needs to be conducted in vivo on human skin.

Despite these limitations, this research has allowed for a difference to be established, providing not only statistical significance but of practical significance also. Practitioners can still select mediums based on personal preference, however there is now purpose behind this. For examples, results suggest that if a high coefficient of friction is desired then wax is ideal, with RockRub© more specifically providing the greatest coefficient of friction. Opposing this, oil providing the lowest coefficient of friction to which olive oil produces the lowest.

To conclude, this study has demonstrated that traditional sports therapy mediums applied to skin cause significantly different effects, reinforcing the already common assumptions of medium that should be utilised for specific therapeutic treatment.

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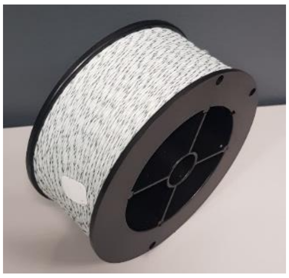
Appendices

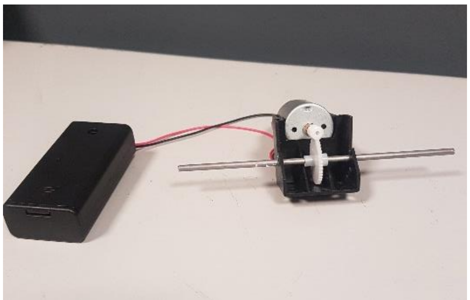
Appendix 1.1 Wireless force-acceleration sensor (PS-3202, PASCO, USA) screwed onto a scientific testing carriage (ME-9454, PASCO, USA)

Appendix 1.2 Braided Physics String (PASCO, USA)

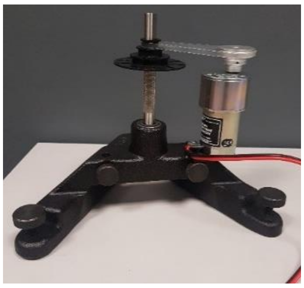


Appendix 1.3 Calibration Weight

Appendix 1.4 Battery-Powered Motor



Appendix 1.5 Rotational motor drive (ME-8955, PASCO, USA) connected to vertical shaft with pulley on a rotating platform (PASCO, USA) via drive belt



Appendix 1.6 DC Programmable Power Supply (PI-9880, PASCO, USA)

Appendix 1.7 Plastic tray (ME-8574, PASCO, USA)

Appendix 2.1 Table of ingredients

Product	Manufacturer	Ingredients
Cream	Baselin	Aqua, paraffinum liquidum, Peg 40 Castor oil, cetearyl alcohol, sodium cetearylsulfate, ethylhexyl glycerine, phenoxyethanol, glycerine, cethyl alcohol, dimethicon, carbomer, amino methyl propanol, fragrance
	Mueller®	Water, mineral oil, glycerol monostearate, cetyl alcohol, tween 80, propylene glycol, lanolin anhydrate, cetyl esters wax NF, methyl paraben, propyl paraben
	Rubbeez®	Water, olive fruit oil (Olea europaea), comfrey (Symphytum officinalis), arnica (Arnica montana), St John's wort (Hypericum perforatum) and calendula (Calendula officinalis) extracts, vegetable glycerine, glycerol stearate, cetearyl alcohol, menthol, sodium stearoyl glutamate, beeswax, phenoxyethanol, ethylhexylglycerine, parfum (natural)
Oil	Grapeseed	Grapeseed Oil (Vitis Vinifera), Vitamin E (Tocopheryl Acetate).
	Olive	Extra virgin olive oil, water, alcohol, emulsifier
	Schupp	Paraffinum Liquidum, simmondsia chinensis seed oil, cetearyl isononanoate, octyldodecanol, oleyl erucate, tocopheryl acetate
Wax	Annie's	Grapeseed Oil (vitis vinifera), Pure natural beeswax (cera flava) & a hint of organic lemon (Citrus Limonum)
	RockRub	Canola oil, beeswax, vitamin E, patchouli, bergamot, lavender, ylang ylang
	Songbird®	Olea europaea fruit oil, prunus amygdalus dulcis oil, cera alba, citrus limon peel oil, leptospermum scorparium oil, hypericum perforatum extract, calendula officinalis extract, arnica montana extract, tocopherol, citral, limonene, linalool